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CORRECTIVE MEASURES STUDY

DUPONT EXPERIMENTAL STATION

DRAFT FINAL REPORT

July 8, 1991

CORRECTIVE MEASURES STUDY
DuPont Experimental Station
Draft Final Report

Prepared for:

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1 INTRODUCTION

E.I. DuPont de Nemours & Co., Inc. (DuPont) entered into a Consent Order on February 15, 1989 with the U.S. Environmental Protection Agency - Region III (EPA) as operator and owner of the Experimental Station in Wilmington, Delaware. One requirement of the Order is to perform a RCRA Facility Investigation (RFI) for a portion of the site to determine fully the presence, magnitude, extent, direction, and rate of movement of any hazardous wastes and/or hazardous constituents from the area of investigation at the facility. The RFI was completed in September of 1990 and was approved by EPA in February of 1991. A second requirement of the Order is to conduct a study of remedial alternatives.

This report presents the results of the study of remedial alternatives. Subsequent to the RFI approval, EPA and DuPont agreed that a Risk Assessment should be performed for the facility. The Risk Assessment was, hence, incorporated into the present study. A brief summary of the Risk Assessment is included in the main portion of this report. The complete Risk Assessment is attached in Appendix 1. The study follows the guidance (U.S. EPA/530-SW-88-028) on preparation of a Corrective Measures Study and the Proposed Rule for Corrective Action for Solid Waste Management Units at Hazardous Waste Management Facilities, Federal Register, 27 July 1990.

This document is submitted as a draft final version. A final version of the report will be prepared after comments are received from U.S. EPA (Region III).

2 SUMMARY

The remedial approach recommended for the facility is designed (1) to minimize exposure of workers to contaminants in soil and (2) to assure that discharge of groundwater to Brandywine Creek is not adversely impacting the water quality of the creek. These objectives were based on the Risk Assessment conducted for the site which utilized information and data collected during the RFI.

The RFI established that volatile organic compounds (VOCs), semi-volatile compounds, and metals are present in the soil below the site. VOCs are found in groundwater and beryllium is found in sediments of the Brandywine Creek. The RFI also characterized the pathways and potential for contaminants to migrate in soil, groundwater, sediments, and surface water (see Figure 2.1).

The RFI analytical data and site characterization information were reviewed to establish constituents of concern and exposure scenarios for the Risk Assessment. For soil, three volatile organic compounds, beryllium, and polynuclear aromatic hydrocarbons (PAHs) were identified as constituents of concern. Ten volatile organic compounds were selected as constituents of concern for groundwater. No constituent of concern was selected for surface water, because site-related compounds were not detected. Beryllium was the only constituent of concern selected for creek sediments.

Because no source for beryllium was identified in the RFI, detailed sampling of the creek sediments was conducted to determine whether the beryllium represented an anomaly or a persistent occurrence. The results indicated that no samples were above detection limits for beryllium.

The Risk Assessment led to the following conclusions:

- No significant risks off-site were identified.
- For present use, the total carcinogenic risk was calculated as 6×10^{-5} for workers. All other carcinogenic risks were below 10^{-5}. However the worker scenario was based on direct contact and ingestion of contaminated soil, which was at depth or under paved areas.

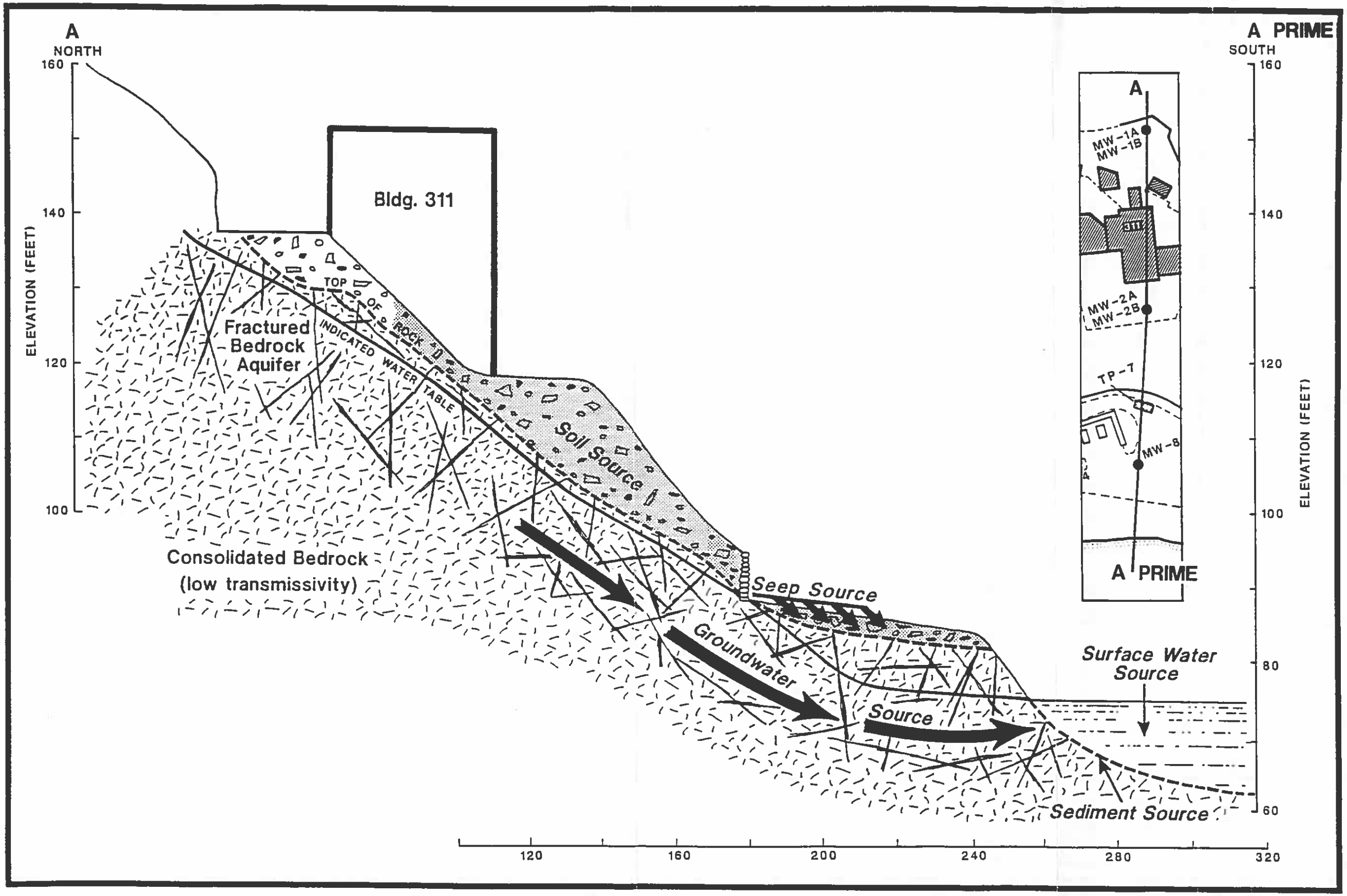

Figure 2.1. The conceptual model of source areas and exposure routes.

- For future use, the calculated total carcinogenic risks were below 10^{-5} except for an improbable drinking water scenario for groundwater.

- The hazards indices for non-carcinogenic health effects were acceptably low for all potential receptors.

The Risk Assessment also provided remedial goals for corrective measures. The remedial goals addressed worker exposure to contaminated soil during excavation activities, the potential use of groundwater for drinking purposes, and the potential for groundwater discharge to adversely impact water quality in Brandywine Creek.

The recommended remedial approach is summarized in Table 2.1. The potential for worker exposure to contaminated soils will be addressed by health and safety protocols that will be followed for any excavation activities. No use of groundwater below the site will be permitted while DuPont maintains control. Future use of on-site groundwater for drinking or other purposes will be limited by deed restrictions. Finally, groundwater discharge to Brandywine Creek will be monitored at nine wells along the creek. If health-based remedial goals are exceeded, contaminated groundwater will be recovered from wells and discharged to the sewer for ultimate treatment. Also, if groundwater remedial goals are exceeded, a prototype soil vapor extraction system will be installed and tested to design a full scale system should it be practicable.

Table 2.1. Corrective measures plan.

MEDIA	IMMEDIATE ACTION	ACTION CRITERIA	CONTINGENT ACTION
Soil	Develop protocols to avoid exposure to contaminated soils during excavation activities.	Any excavation in site area.	Apply excavation protocols.
Groundwater	Monitor for volatile compounds in groundwater. Develop remedial contingency plan. • Groundwater recovery system. • Prototype soil vapor extraction system. Place deed restrictions on use of groundwater below the site.	• Health-based remedial goals for impact on creek. • Retest if exceeded. • If exceeded on retest, implement remedial contingency plan.	• Install and operate groundwater recovery system until groundwater concentrations are less than 50% of remedial goals. • Install and test prototype soil vapor extraction system. Based on test results design, install, and operate soil vapor extraction system, if practicable.

3 FACILITY DESCRIPTION

3.1 SITE DESCRIPTION

The E.I. DuPont de Nemours & Company Experimental Station is located in New Castle County, Delaware, four miles northwest of downtown Wilmington, along Route 141. The facility is situated in the Brandywine Valley along the banks of the Brandywine Creek as shown in Figure 3.1. The Experimental Station is the central research and development facility for DuPont.

The area of investigation is a portion of the Experimental Station property. It is bounded by the Brandywine River to the south. Otherwise, the area is surrounded by property owned and controlled by DuPont as shown in Figure 3.1. The area contains several buildings, paved roads, and paved parking areas situated on the steep hillside.

The subsurface materials consists of bedrock overlain by overburden consisting of a mixture of colluvium and fill material. The thickness of the overburden ranges from absent (at numerous bedrock outcrops) to 18 feet. The bedrock is a hard banden gneiss with narrow widely spaced joints. The bedrock surface slopes toward the river.

Groundwater below the site occurs at or near the interface between the bedrock and overburden. A few feet below this interface the bedrock has very low permeability. Infiltration from rain fall recharges the thin groundwater flow zone, which discharges at seeps along the road and to the Brandywine Creek.

3.2 SITE HISTORY

The site has been active as a research facility for approximately 90 years. Prior to this, the area along the Brandywine Creek was used in the 1800's for gun powder manufacture by DuPont. Relic structures of these facilities are still in existence along the river front. Presently, the facility employs 5,000 chemists, engineers and technicians dedicated to product development and basic research.

Review of the Experimental Station files and available aerial photographs revealed little detailed information about former site

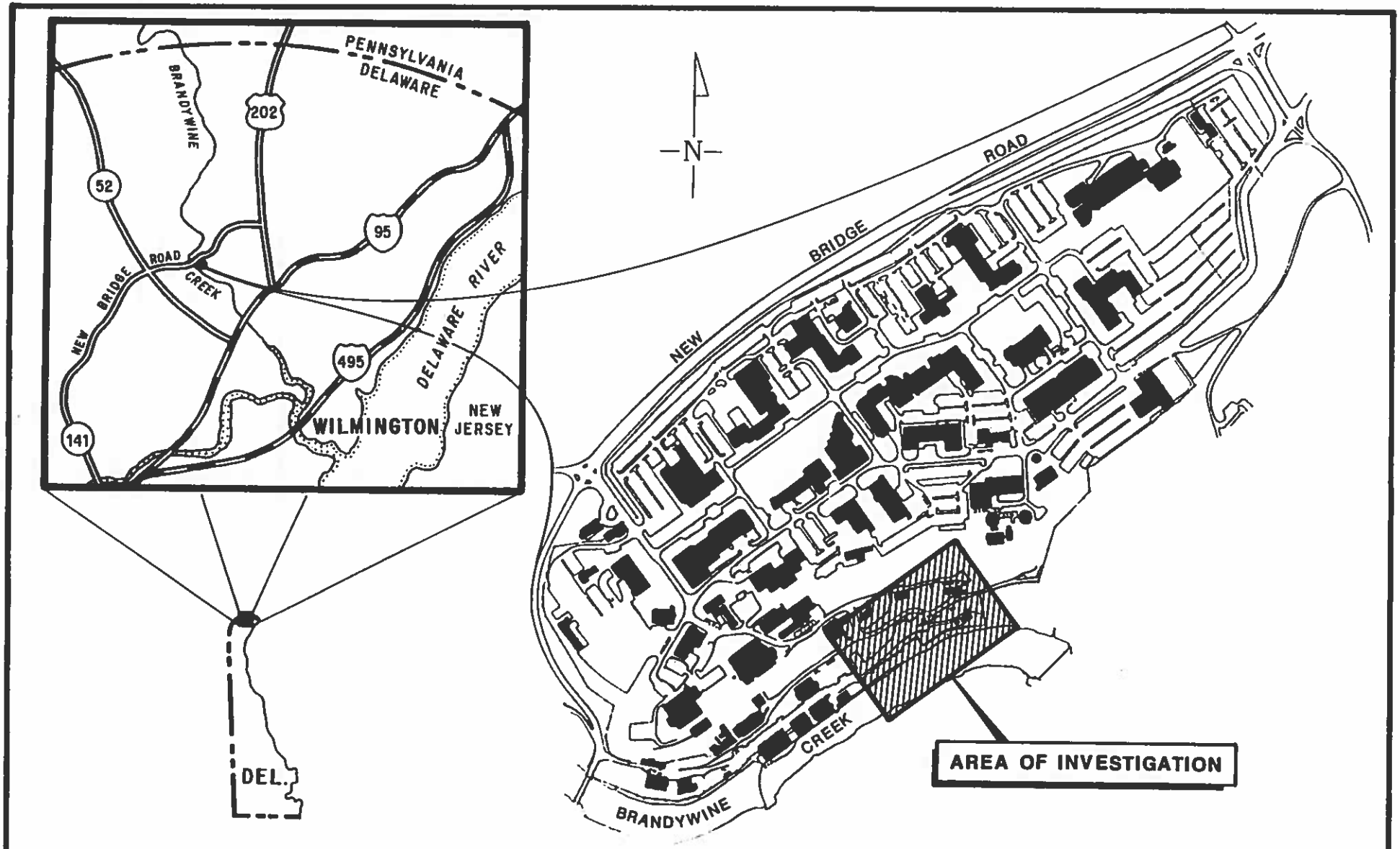

Figure 3.1. Location of du Pont Experimental Station and the RFI area of investigation.

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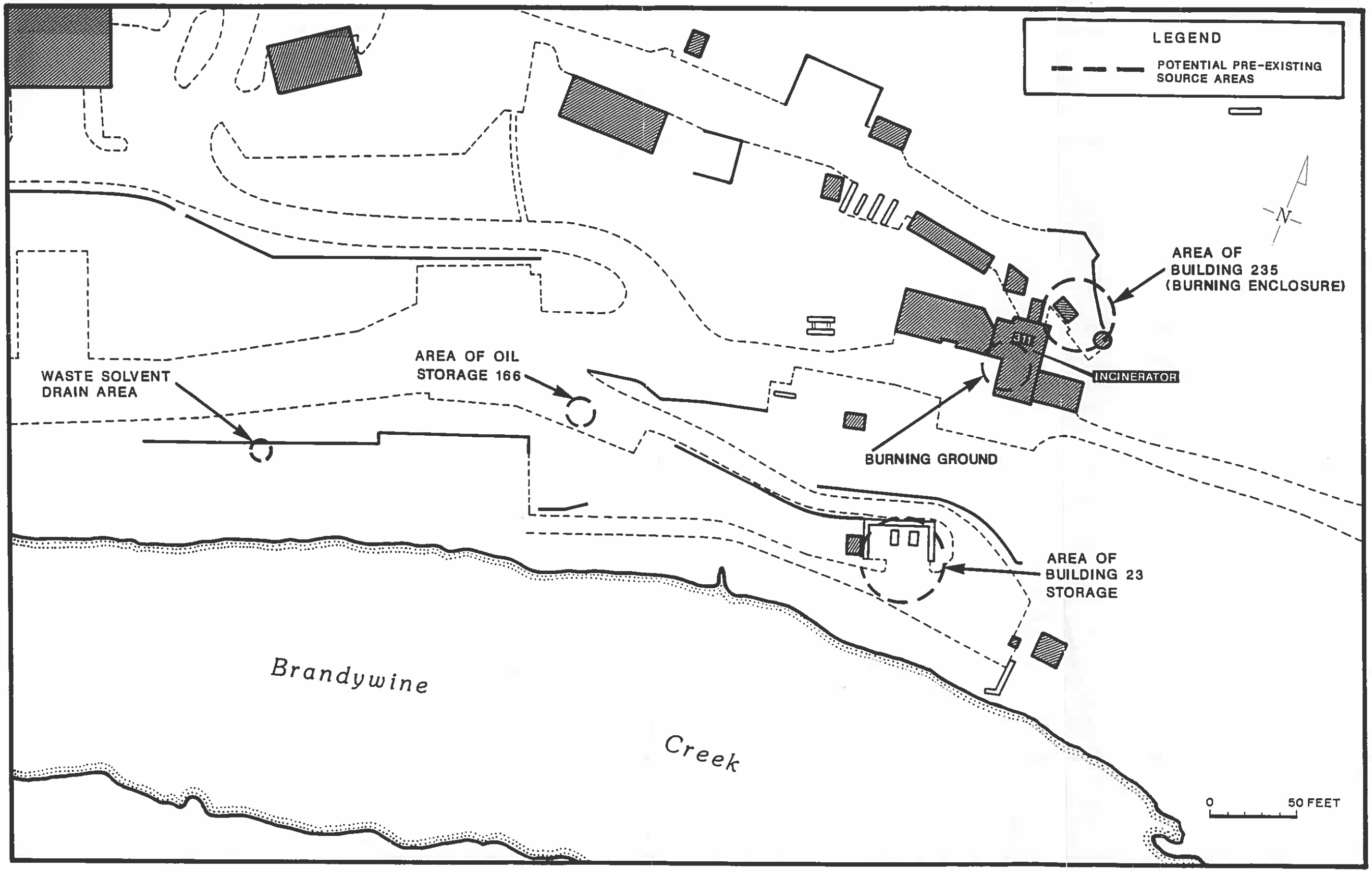

Figure 3.2. General area of potential pre-existing source areas compiled from site archives.

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activities that may be associated with the contamination sources. The only reference to possible original source areas is found on site blueprints from the 1940's. The pertinent information from these blueprints is compiled on Figure 3.2. Three storage areas are identified: oil storage 166; building 23 storage; and building 235 (burning enclosure). There are no available records to indicate what materials were stored in these areas. An area identified as a "burning ground" was located just south of the burning enclosure. Based on the available information in the files, the area was used as a burning area for solvents.

According to site files fill material in parking areas and some road beds in the area may have consisted of ash and other fill material obtained from the old burning ground area. The filling of that area was probably associated with the demolition and removal of building 255, which apparently occurred sometime between 1948 and 1955, according to blueprint information.

Soil contamination was found near building 311 during utility excavation activities in 1986. This discovery led to a series of field investigations of which the most recent was the RCRA Facility Investigation.

A brief chronology of site activities associated with the recent discovery of the soils and groundwater contamination follows:

Date	Event
May - July 1986	Utility excavation in the vicinity of Building 311 reveals the presence of soils and groundwater contamination. Duffield Associates, environmental consultants, perform a study which includes the installation of monitor wells and soil and groundwater sampling. The State of Delaware and USEPA are informed of the findings.
April 1987	Utility excavation at the intersection of Creek and "C" roads reveals the presence of another area of soil contamination. Analysis of the site reveals that the problem is, also, probably associated with backfill obtained from the incinerator area.

May 1987	DuPont informs the USEPA about the problem.
June 1987	Contaminated soils from Creek Road area are removed from the site.
February 1989	Consent Order to conduct a RCRA Facility Investigation (RFI) at the site is signed.
December 1989 - September 1990	RFI conducted.
February 1991	RFI approved.

4 SUMMARY OF RFI AND RECENT SEDIMENT SAMPLING

The RFI for the site was conducted between December 1989 and September 1990. The investigation was based on the requirements of the Consent Order of February 15, 1989 between EPA and E.I. DuPont de Nemours & Co.

The work consisted of: (1) review of available background information pertaining to waste handling at the facility; (2) field investigation to characterize source areas of contamination; (3) field investigation to characterize contaminant extent and movement within the environment; (4) analysis of the data collected; and (5) identification of potential receptors. To focus the present corrective measures analysis, a risk assessment based on the RFI results was conducted and is included as Appendix 1. A summary of both the RFI and the recent sediment sampling is provided here as background.

4.1 FIELD STUDIES

The field studies had two objectives (1) to characterize source areas, and (2) to characterize the extent and movement of contaminants in groundwater. The field work included the following activities:

- A soil gas survey was conducted to focus soil sampling activities (45 samples and analyses for selected volatile compounds were obtained).
- Soil sampling and analysis was preformed to identify source areas and define contaminant extent in soils. Samples (32) were collected at 24 locations by hand augering and split spoon sampling. Another 15 samples were collected at 8 test pits. The split spoon auger samples were analyzed for volatile organic compounds (VOCs), biphenyl, and biphenyl oxide. The test pits were sampled for base neutral compounds, biphenyl and biphenyl oxide. Two of the split spoon samples and two of the test pit samples were analyzed for the comprehensive Appendix IX list of analytes.
- A fracture/structural survey was made of the frequency an orientation of joints (fractures), in order to evaluate their potential to serve as contaminant pathways and to aid in locating wells.

- Ten monitor wells were installed in the bedrock at various depths to supplement four wells that already existed in the vicinity of the site.

- Video and geophysical surveys were conducted to help identify flow zones in wells. The video surveys were conducted in the nine wells which were open. The geophysical surveys were conducted in all fourteen on-site wells. Geophysical test included: caliper, gamma, electric, temperature, fluid conductivity, neutron, and grout density.

- Two types of aquifer tests were conducted. Slug tests were conducted in all fourteen wells and injection tests were conducted in 5 wells.

- Dye tracers were placed in two wells and monitored in several wells to evaluate migration pathways at the site.

- Groundwater elevations were measured on twelve occasions over four months to assess groundwater flow directions and gradients.

- Groundwater samples were collected at all fourteen wells in two rounds. In round one, samples were analyzed for VOCs, biphenyl and biphenyl oxide. Four of the samples at two wells were analyzed for Appendix IX analytes. In the second round only VOCs were analyzed.

- Surface water and sediments sampled at four locations were analyzed for VOCs, metals, biphenyl and biphenyl oxide.

4.2 RESULTS OF SAMPLING AND ANALYSIS

4.2.1 Source Area

Although several potential sources were identified as part of the records search, only two sources have been confirmed by the sampling investigation. The primary source area for VOCs and polynuclear aromatic hydrocarbons (PAHs) appears to be the former burning area near Building 311. The secondary source is along Creek Road where ash from the burning ground was most likely used as fill material when the former Building 255 was demolished and removed sometime between 1948 and 1955. Samples of soils in the vicinity of the former burning ground were consistently higher in concentrations of PAHs and VOCs than other areas of the site. More convincingly though, the highest

concentrations of VOCs in groundwater occur below areas between the burning ground and the creek.

Fill material used for roadbeds and parking areas most likely was borrowed from the burning ground area. The types of constituents found in the two areas are similar. Where ash material has been sampled from the fill, its concentrations of PAHs and VOCs are as high as those observed in the burning ground area. The similarity in both the types of contaminants and the concentrations indicates a common source for the burning ground material and the ash in fill areas along Creek Road.

The contaminants observed in soil and groundwater would be expected to be present below an area used for burning spent solvents and other materials. Additionally, residual material from the burning operations would have formed ash.

4.2.2 Extent and Levels of Contamination in Soils

Detectable levels of PAHs, VOCs, pesticides, and metals are present in many of the soil samples. With the exception of PAHs, none of the contaminant classes present any significant concern at the site. Tables 4.1 and 4.2 show maximum concentrations of VOCs and metals that have been found in on-site soils. For comparison purposes, those maximum concentrations are compared with action levels set forth in EPA's Proposed Rule (Federal Register, July 27, 1990). EPA has not set action levels for any of the semivolatile components detected on site.

The occurrence of the soil contamination correlates with (1) the presence of fill material that includes ash, and (2) the location of the former burning ground. The majority of the fill material is covered by pavement. In fact, each of the samples containing more than 10 mg/kg of total semivolatiles was obtained from a sample site covered by pavement. Figures 4.1 and 4.2 show the soil results for total volatile compounds and total semivolatile compounds.

Table 4.1. Maximum concentrations (µg/kg) of volatile organic compounds detected in soil samples.

Constituent	Max Value	Location	Action Level[1]
1,1,1-Trichloroethane	55	f-4a	700,000
1,1,2-Trichloroethane	160	c-2	100,000
1,1-Dichloroethene	240	c-2	8,000
Acetone	94	k-2	8,000,000
Acrolein	4	tbl2/14	--
Acrylonitrile	5	tbl2/14	1,000
Carbon disulfide	1	k-2	8,000,000
Chloroform	34	e-2	100,000
-Ethylbenzene	190	c-2	8,000,000
-Methylene Chloride	720	c-2	90,000
Tetrachloroethene	13000	c-2	10,000
-Toluene	290	c-2	20,000,000
Trans-1,2-Dichloroethene	4000	c-2	--
-Trichloroethene	30000	c-2	60,000
-Xylenes	1	k-2	200,000,000

***Note: chemicals never found above detection are not included here.

[1]Federal Register, Appendix A, Volume 55, No. 145, July 27, 1990

Table 4.2. Maximum concentrations (mg/kg) of metals detected in soil samples.

	Max Value	Location	Action Level[1]
Arsenic	18.4	tp-6:3′	80
Barium	154	k-2	4000
Beryllium	0.41	tp-2a	0.2
Cadmium	3.8	tp-2a	40
Chromium	49.4	m-comp	400
Cobalt	19	tp-6:3′	--
Copper	173	k-2	--
Lead	73.5	k-2	--
Mercury	3	tp-2a	20
Nickel	30.1	k-2	2000
Selenium	0.68	tp-7b	--
Silver	2.21	k-2	200
Vanadium	57.3	tp-7b	--
Zinc	165	k-2	--

***Note: metals never found above detection are not included here.

[1]Federal Register, Appendix A, Volume 55, No. 145, July 27, 1990

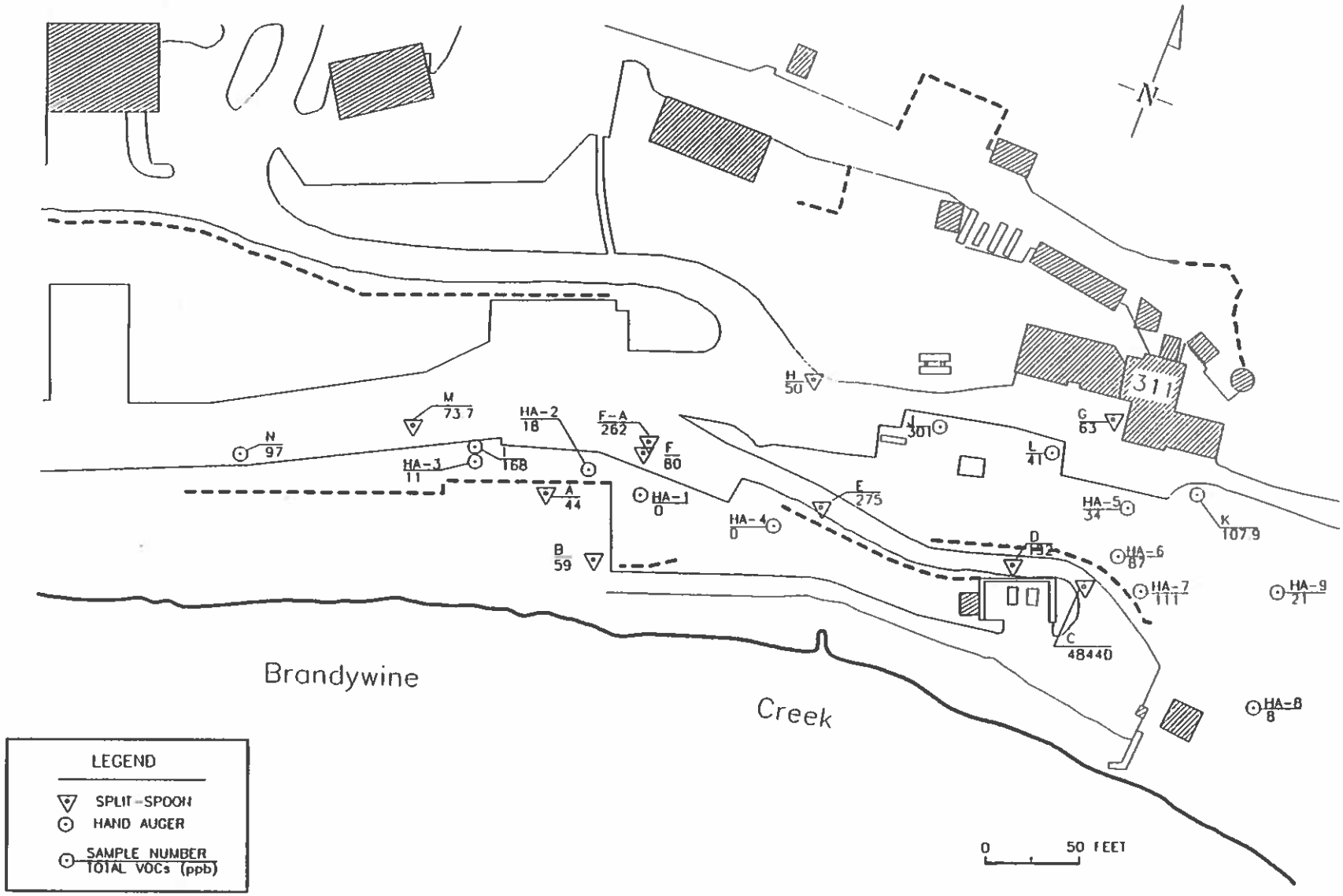

Figure 4.1. Total volatile organic compounds in soils (ppb) from Phase I and Phase II sampling.

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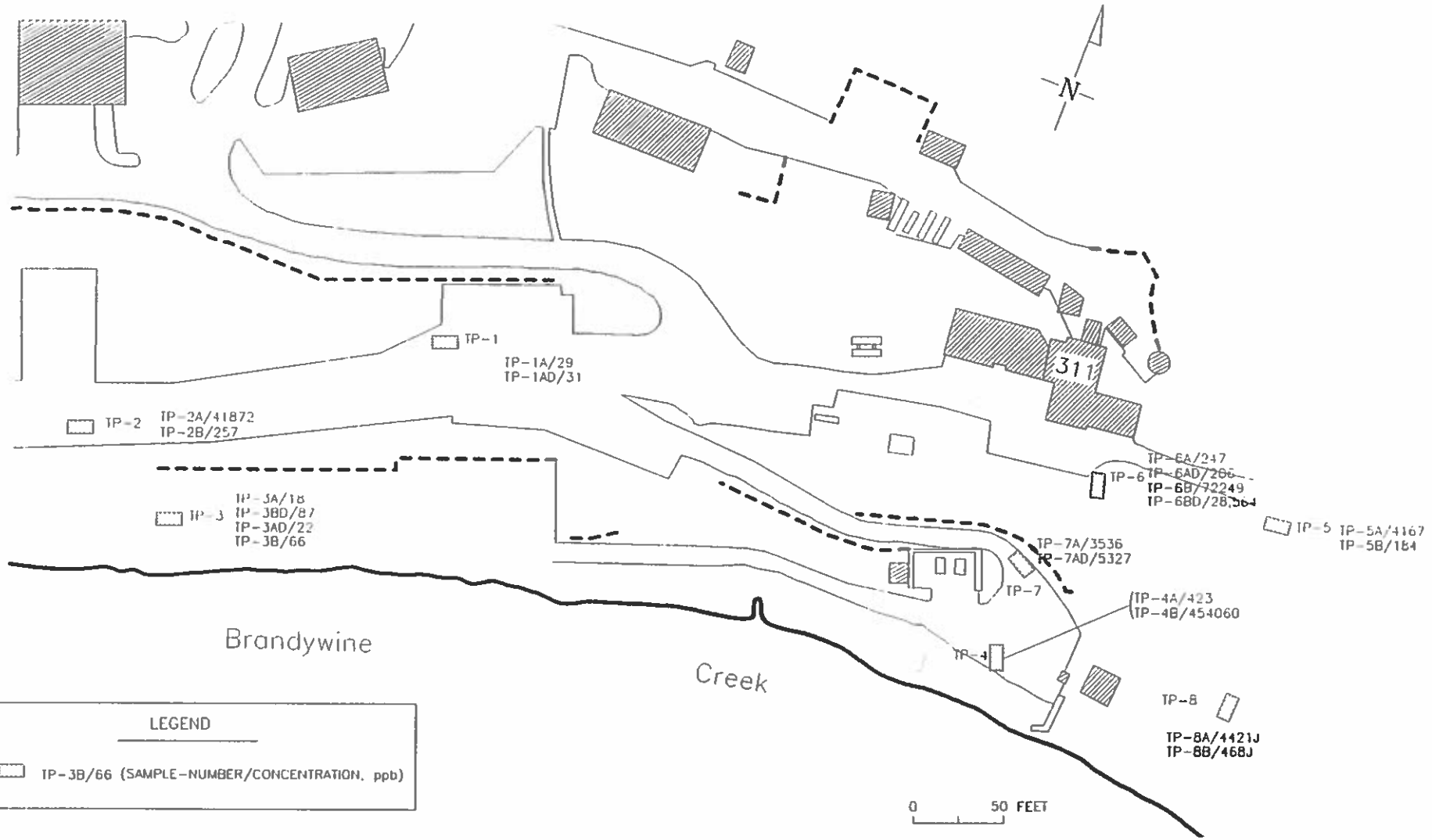

Figure 4.2. Total semivolatile compounds in soils (ppb) from Phase I and Phase II sampling.

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4.2.3 Extent and Levels of Contaminants in Groundwater

Groundwater below the site contains volatile compounds at concentrations that exceed action levels in EPA's Proposed Rule and exceed MCLs (Figure 4.3 and Table 4.3). The highest concentrations occur in the area between the former burning ground and Brandywine Creek. The relatively high concentrations in this area point to the former burning ground as the source area. The lack of significant concentration of VOCs in the two wells upgradient of the former burning ground further confirms the source identification.

Other constituents detected in groundwater include low levels of biphenyl, biphenyl oxide, thalates, lead, zinc, and 1,2-dichlorobenzene. None of these constituents occurs above the levels of concern.

The maximum VOC concentration observed was 7700 µg/L of trichloroethene. The MCL for this constituent is 5 µg/L. The MCL is based on the assumption that the groundwater will be used for drinking purposes. However, groundwater at the site is in a thin, low-yielding water-bearing strata and, therefore, cannot be used for drinking purposes.

4.2.4 Extent and Levels of Contaminants in Sediments and Surface Water

No contaminants were detected in the samples of surface water. Only methylene chloride was reported above detection limits. However, methylene chloride also was reported for blanks, thus the results are not reliable.

Sediment samples contained low levels of VOCs, biphenyls, biphenyl oxide, and metals. The VOCs are observed in areas that would receive surface drainage and groundwater discharge from the former burning ground area. The highest levels of metals are found in the sample taken at the western edge of the study area (Station 2). Beryllium (at one location) is the only metal that exceeds the soil action level set forth in EPA's Proposed Rule. The lack of detectable levels of contaminants in the surface water confirms that discharge of groundwater from the site has no impact on water quality in Brandywine Creek.

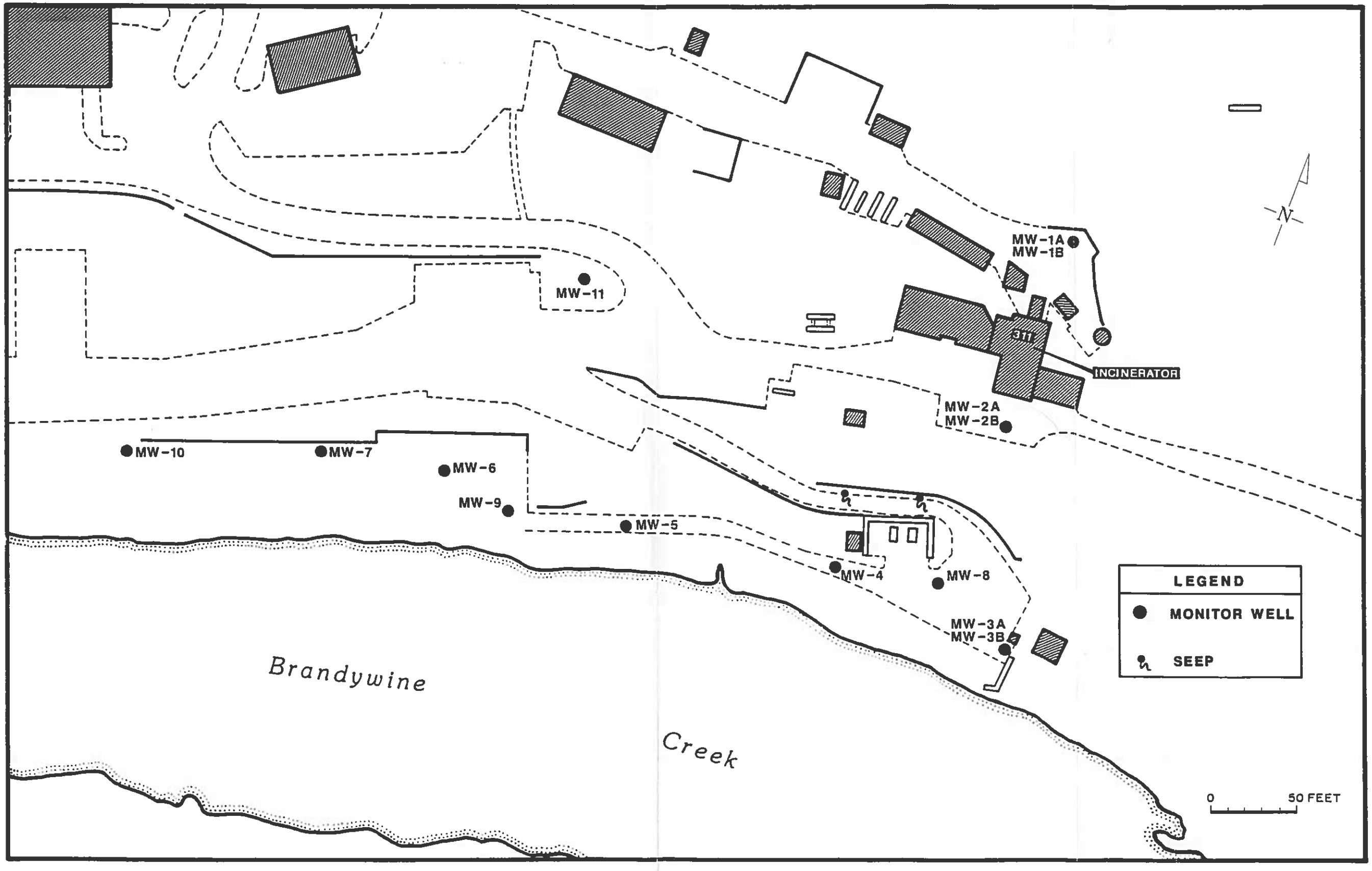

Figure 4.3. Location of monitor wells and groundwater seeps.

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Table 4.3. Total volatile organic compounds and semivolatile compounds in groundwater.

Well ID	Open Interval (ft-ft)	Total VOCs (ppb) Round 1	Total VOCs (ppb) Round 2	Total Semi-volatile[1] (ppb) Round 1[2]	Biphenyl/ Biphenyl Oxide (ppb) Round 1[2]
MW-1A	10 - 39	4	ND	NA	ND
MW-1B	42 - 102	13	3	NA	ND
MW-2A	20 - 22	630	2151	NA	363
MW-2A	20 - 22	NA	2162	NA	ND
MW-2B	42 - 81	8904[1]	10060	35	ND
MW-3A	5 - 20	752	383	NA	ND
MW-3A	5 - 20	708	419	NA	ND
MW-3B	26 - 39	11090[1]	6803	16	ND
MW-4	13 - 21	47	166	NA	ND
MW-5	8 - 20	11	19	NA	ND
MW-6	8 - 20	373	714	NA	ND
MW-7	11 - 40	118[1]	27	9	ND
MW-8	8 - 19	1882[1]	1137	3.9	ND
MW-9	8 - 19	7	10	NA	ND
MW-10	9 - 42	13	8	NA	ND
MW-11	8 - 20	201	5	NA	ND

[1]Appendix IX list
[2]Samples collected under Round 2 were analyzed for VOCs only
ND - Not Detected
NA - Not Analyzed

4.3 HYDROGEOLOGIC ANALYSIS

The hydrogeologic setting at the site is characterized by a saturated, low-permeability bedrock aquifer and a variably-saturated zone in the overburden. Groundwater flow is primarily through fractures and along the overburden/bedrock interface. Permeability in the bedrock aquifer appears to decrease with depth as evidenced by the slow recovery rate observed in deep wells MW-1B and MW-2B during aquifer testing. Additionally, tracer test results showed little or no movement of the Fluorescein dye from well MW-2B.

Aquifer test results for slug tests and pumping tests demonstrate the variability in hydraulic properties over the relatively small area of investigation. Estimated hydraulic conductivity values range over five orders of magnitude.

Numerous water-level surveys demonstrate that groundwater consistently flows toward Brandywine Creek in all sections of the area of investigation. In fracture dominated flow, discrete flow paths may turn in many directions before reaching the main discharge boundary. However, based on the structural survey, flow paths at the site should trend primarily northwest-southeast toward the river. This is supported by pumping test results and tracer test results that show progressively less hydraulic connection between MW-2A and other site wells with increasing distance to the southwest. For example, good hydraulic connection exists between well MW-2A and wells MW-3A, MW-3B; moderate connection is observed between MW-2A and MW-8 and MW-4; and no connection is observed between MW-2A and the remaining wells. The occurrence of two seeps behind storage area 23, where bedrock is close to ground surface, is evidence that some groundwater travels along the overburden/bedrock interface. The detection of Rhodamine dye in the seeps during the tracer tests indicates a hydraulic connection to the aquifer in the vicinity of MW-2A.

All together the data suggest that groundwater in the vicinity of the incinerator discharges directly to the river along a northwest/southeast-trending zone. Discrete groundwater flow paths in the area west of the incinerator can not be identified because of the lack of observable responses during pumping tests and tracer tests.

Any groundwater discharged from the study area will mix with and be diluted by the creek water. The 42 year record indicates that the average flow has been 477 cubic feet per second. The minimum daily discharge during the period of record was 50 cubic feet per second.

The geometry of the water bearing zone and available groundwater and surface water elevation data clearly demonstrate that groundwater below the study area discharges to Brandywine Creek. On the other hand, the quantity of groundwater flow is not so readily evaluated. Typical of fractured and low permeability hydrogeologic units, the aquifer testing showed a high degree of heterogeneity (i.e. transmissivity values ranging over 5 orders of magnitude). The extreme heterogeneity makes direct estimation of groundwater discharge difficult. Stochastic groundwater flow analysis was used to evaluate the potential range of groundwater discharge to Brandywine Creek. A sequence of 50 groundwater flow simulations based on different permeability distribution were conducted. Details of the approach are provided in the RFI.

The primary result of interest was discharge to Brandywine Creek. From the 50 simulations, the maximum discharge to the creek is 4345 ft^3/d (0.05 ft^3/s) and the minimum is 2022 ft^3/d (0.0234 ft^3/s). This discharge is small in comparison to the flow in the creek. As noted flow in the Brandywine Creek has averaged 477 ft^3/s over the 42 year period of record. Thus, the average flow in the creek is about 10,000 times greater than groundwater discharge to the creek from the study area.

4.4 RECENT SEDIMENT SAMPLING

Beryllium was detected at one of the sediment samples above action levels in the Proposed Rule. Because no on-site source was apparent, the sediments in the vicinity of the original sample station where beryllium was detected were resampled. The locations of 20 sediment-samples are shown in Figure 4.4. The results (Table 4.4) indicated that no samples were above detection limits (1 mg/kg on as received basis or from slightly greater when converted to a dry weight sample basis).

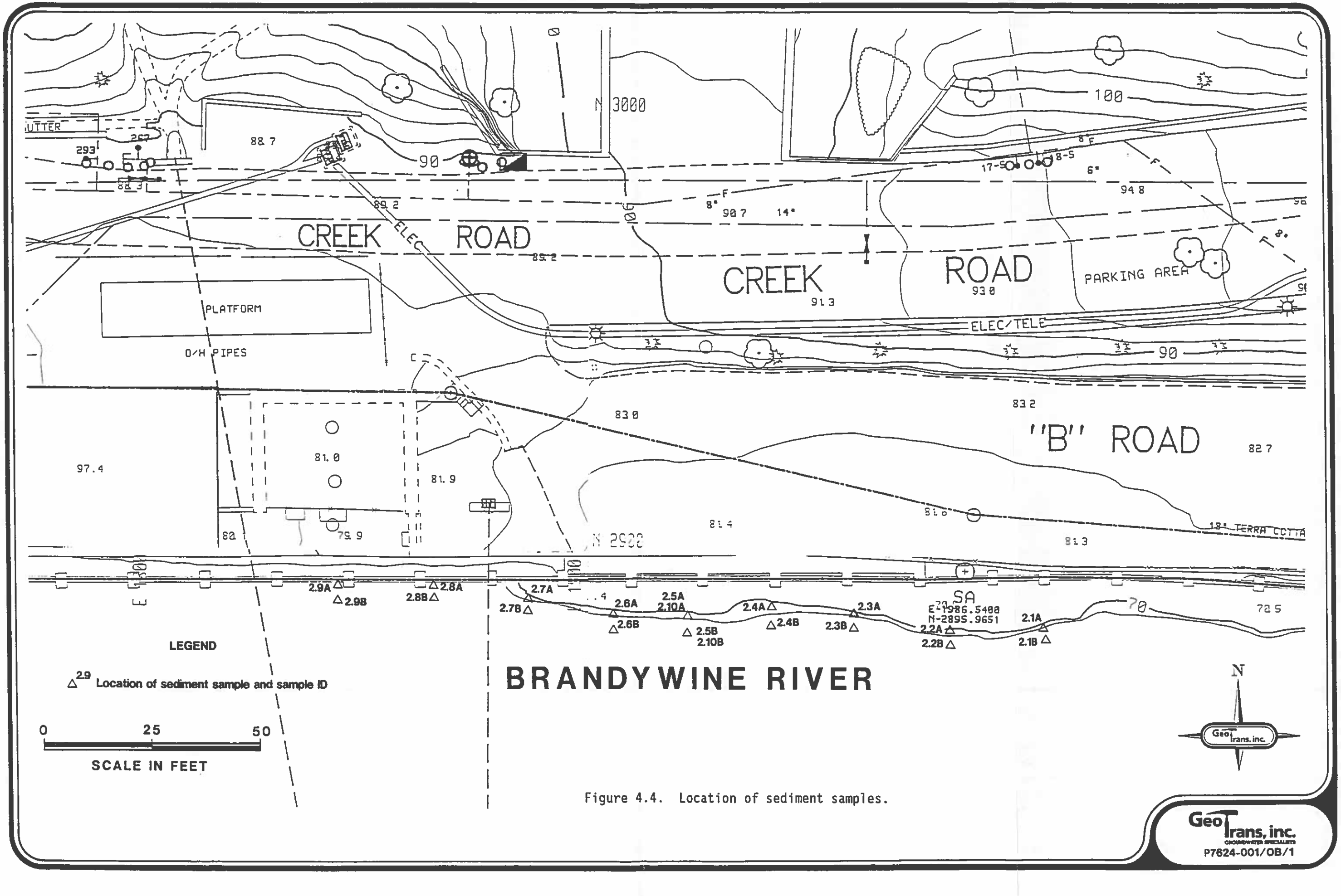

Figure 4.4. Location of sediment samples.

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Table 4.4. Beryllium concentration and moisture content of sediment samples at the du Pont Experimental Station.

Sample ID	Dry Wt. Basis Concentration (mg/Kg)	Limit of Quantitation[b]	Moisture Content (% by weight)
2.1A	<1	1.0	32.2
2.2A	<2	2.0	35.3
2.3A	<2	2.0	38.1
2.4A	<2	2.0	52.5
2.5A	<1	1.0	29.0
2.6A	<1	1.0	24.3
2.7A	<1	1.0	27.5
2.8A	<2	2.0	41.9
2.9A	<1	1.0	29.1
2.10A	<1	1.0	29.9
2.1B	<2	2.0	37.1
2.2B	<3	3.0	63.9
2.3B	<2	2.0	39.2
2.4B	<2	2.0	38.0
2.5B	<2	2.0	42.7
2.6B	<1	1.0	25.7
2.7B	<1	1.0	27.6
2.8B	<1	1.0	26.9
2.9B	<1	1.0	30.1
2.10B	<2	2.0	40.4
Eq Blank[a]	<0.005	0.005	NA

[a] The Equipment Rinsate Blank Sample was a water sample. Moisture content determination did not apply.

[b] Limit of Quantitation for all samples as received is 1 mg/Kg. Limit of Quantitation was increased in some samples after conversion to dry weight basis due to high moisture content.

5 RISK ANALYSIS

A risk assessment of the site was performed to determine the need and extent of corrective measures. The study is attached as Appendix 1. A brief summary is provided here because it serves as the starting point for development of the corrective measures plan for the site.

The risk assessment was performed by Karch & Associates, Inc. (Washington, DC) using guidance materials from EPA's Superfund program. Among the documents consulted were the Risk Assessment Guidelines for Superfund (EPA 1989a) the Superfund Exposure Assessment Manual (EPA 1988), The Superfund Public Health Evaluation Manual (EPA 1986), and the Exposures Factors Handbook (EPA 1986). Following EPA policy, reasonable maximum exposure estimates were developed for the site.

5.1 SELECTION OF CONTAMINANTS OF CONCERN

The selection of contaminants of concern was based on Action Levels established in the proposed Corrective Action Rule for Solid Waste Management Units (Federal Register, 27 July 1990). Any compound detected at a maximum concentration greater than the Action Level was included as a contaminant of concern. Other appropriate standards were used when no Action Level existed in the Corrective Action Rule. Two contaminants in soil were included at EPA's request. Five contaminants of concern were identified in soils, ten in ground water and one in sediments. Table 5.1 provides a list of the chemicals of concern.

5.2 RISK EVALUATION

A risk assessment based on estimating a Reasonable Maximum Exposure (RME) was conducted following EPA Guidance and the National Contingency Plan. Potential receptors included industrial workers, recreational users of the area, and area residents. Exposures to soil, surface water, sediments, and volatilized chemicals in soil and ground water were evaluated, as appropriate. The exposure scenarios are indicated in Table 5.2. The results of the risk assessment are summarized in Tables 5.3 and 5.4. Table 5.3 provides the estimated

Table 5.1. Chemicals of concern at the DuPont Experimental Station Site.

Soil	
Beryllium	Methylene chloride
PAHs (Benzo[a]phyrene)	Tetrachloroethene
Trichloroethene	
Ground Water	
Benzene	α-Benzene hexachloride
Carbon tetrachloride	trans-1,2-Dichloroethene
Methylene chloride	1,1,2,2-Tetrachloroethane
Tetrachloroethene	1,1,2-Trichloroethane
Trichloroethene	Vinyl chloride
Surface Water (Brandywine Creek)	
No contaminants detected above detection limits	
Sediments	
Beryllium	

Table 5.2. Summary of exposure scenarios for the DuPont Experimental Station Site Risk Assessment.

Industrial Workers (Current Use)
Dermal contact with soil
Inadvertent ingestion of soil
Inhalation of volatiles VOCs from soil
Inhalation of volatilized VOCs from seep water
Recreational Users (Future Use)
*Dermal exposure to surface water while swimming
*Ingestion of surface water while swimming
Dermal contact with sediments in Brandywine Creek
Dermal contact with soil
Inadvertent ingestion of soil
Inhalation of volatilized VOCs from soil
Inhalation of volatilized VOCs from seep water
Area Residents (Current and Future Use)
*Ingestion of drinking water from Brandywine Creek

*An asterisk indicates a pathway where risks cannot be calculated because no contaminants were found at detectable levels.

GeoTrans, inc.
ENVIRONMENTAL SPECIALISTS

46050 Manekin Plaza
Suite 100
Sterling, VA 22170

LETTER OF TRANSMITTAL

DATE	7/11/91	JOB NO	7624-001
RE:	CMS - Experimental Station		

TO: Mr. Robert Stroud
EPA Region III

ATTN:

WE ARE SENDING YOU: ☐ Attached

☐ Artwork ☐ Under separate cover via _____, the following items:

☐ Drawings ☐ Contract ☐ Report ☐ Samples ☐ Work Assignment

☐ Copy of letter ☐ Reprints ☐ _____

COPIES	DATE	NO.	DESCRIPTION
3			Replacement page 28

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REMARKS: Total risk for "Recreational Users - Adults" was changed from 2×10^{-4} to 2×10^{-6}

COPY TO: C. Chien
B. Farnum
G. Lee
B. Porter

GeoTrans, inc.
ENVIRONMENTAL SPECIALISTS

signed: Lisa L Cuyat

FILE:

If enclosures are not as noted, kindly notify us at once

Table 5.3. Summary of estimated carcinogenic risks for all receptors at the experimental station site.

Constituent	Inhalation Risk	Non-inhal. Risk	Total Risk
INDUSTRIAL WORKERS			
Benzene	2.5×10^{-8}	---	2.5×10^{-8}
Beryllium	---	2.3×10^{-6}	2.3×10^{-6}
Methylene chloride	9.2×10^{-11}	5.9×10^{-10}	6.9×10^{-10}
PAHs	1.9×10^{-16}	5.5×10^{-5}	5.5×10^{-5}
1,1,2,2-Tetrachloroethane	4.1×10^{-8}	---	4.1×10^{-8}
Tetrachloroethene	3.3×10^{-10}	5.2×10^{-8}	5.3×10^{-8}
Trichloroethene	1.8×10^{-9}	2.6×10^{-8}	2.8×10^{-8}
Vinyl chloride	3.6×10^{-7}	---	3.6×10^{-7}
	Total Carcinogenic Risk:		6×10^{-5}
RECREATIONAL USERS - Adults			
Benzene	1.9×10^{-10}	---	1.9×10^{-10}
Beryllium	---	6.2×10^{-7}	6.2×10^{-7}
Methylene chloride	7.0×10^{-13}	2.0×10^{-11}	2.0×10^{-11}
PAHs	1.4×10^{-18}	1.4×10^{-6}	1.4×10^{-6}
1,1,2,2-Tetrachloroethane	3.2×10^{-10}	---	3.2×10^{-10}
Tetrachloroethene	2.5×10^{-12}	1.7×10^{-9}	1.7×10^{-9}
Trichloroethene	1.3×10^{-11}	8.6×10^{-10}	8.7×10^{-10}
Vinyl chloride	2.8×10^{-9}	---	2.8×10^{-9}
	Total Carcinogenic Risk:		2×10^{-6}
RECREATIONAL USERS - Children			
Benzene	1.3×10^{-10}	---	1.3×10^{-10}
Beryllium	---	2.4×10^{-7}	2.4×10^{-7}
Methylene chloride	4.8×10^{-13}	1.4×10^{-11}	1.4×10^{-11}
PAHs	9.7×10^{-19}	1.1×10^{-6}	1.1×10^{-6}
1,1,2,2-Tetrachloroethane	2.1×10^{-10}	---	2.1×10^{-10}
Tetrachloroethene	1.7×10^{-12}	1.2×10^{-9}	1.2×10^{-9}
Trichloroethene	9.1×10^{-12}	6.0×10^{-10}	6.1×10^{-10}
Vinyl chloride	1.9×10^{-9}	---	1.9×10^{-9}
	Total Carcinogenic Risk:		1×10^{-6}

Table 5.3. Summary of estimated carcinogenic risks for all receptors at the experimental station site.

Constituent	Inhalation Risk	Non-inhal. Risk	Total Risk
INDUSTRIAL WORKERS			
Benzene	2.5×10^{-8}	---	2.5×10^{-8}
Beryllium	---	2.3×10^{-6}	2.3×10^{-6}
Methylene chloride	9.2×10^{-11}	5.9×10^{-10}	6.9×10^{-10}
PAHs	1.9×10^{-16}	5.5×10^{-5}	5.5×10^{-5}
1,1,2,2-Tetrachloroethane	4.1×10^{-8}	---	4.1×10^{-8}
Tetrachloroethene	3.3×10^{-10}	5.2×10^{-8}	5.3×10^{-8}
Trichloroethene	1.8×10^{-9}	2.6×10^{-8}	2.8×10^{-8}
Vinyl chloride	3.6×10^{-7}	---	3.6×10^{-7}
	Total Carcinogenic Risk:		6×10^{-5}
RECREATIONAL USERS - Adults			
Benzene	1.9×10^{-10}	---	1.9×10^{-10}
Beryllium	---	6.2×10^{-7}	6.2×10^{-7}
Methylene chloride	7.0×10^{-13}	2.0×10^{-11}	2.0×10^{-11}
PAHs	1.4×10^{-18}	1.4×10^{-6}	1.4×10^{-6}
1,1,2,2-Tetrachloroethane	3.2×10^{-10}	---	3.2×10^{-10}
Tetrachloroethene	2.5×10^{-12}	1.7×10^{-9}	1.7×10^{-9}
Trichloroethene	1.3×10^{-11}	8.6×10^{-10}	8.7×10^{-10}
Vinyl chloride	2.8×10^{-9}	---	2.8×10^{-9}
	Total Carcinogenic Risk:		2×10^{-4}
RECREATIONAL USERS - Children			
Benzene	1.3×10^{-10}	---	1.3×10^{-10}
Beryllium	---	2.4×10^{-7}	2.4×10^{-7}
Methylene chloride	4.8×10^{-13}	1.4×10^{-11}	1.4×10^{-11}
PAHs	9.7×10^{-19}	1.1×10^{-6}	1.1×10^{-6}
1,1,2,2-Tetrachloroethane	2.1×10^{-10}	---	2.1×10^{-10}
Tetrachloroethene	1.7×10^{-12}	1.2×10^{-9}	1.2×10^{-9}
Trichloroethene	9.1×10^{-12}	6.0×10^{-10}	6.1×10^{-10}
Vinyl chloride	1.9×10^{-9}	---	1.9×10^{-9}
	Total Carcinogenic Risk:		1×10^{-6}

Table 5.4. Summary of estimated hazard indices for all receptors at the experimental station site.

Constituent		Hazard Index
INDUSTRIAL WORKERS		
Beryllium		1.9×10^{-4}
Methylene chloride		2.3×10^{-6}
Tetrachloroethene		1.8×10^{-4}
	Total hazard Index:	4.4×10^{-4}
RECREATIONAL USERS - Adult		
Beryllium		6.8×10^{-5}
Methylene chloride		1.0×10^{-7}
Tetrachloroethene		7.9×10^{-6}
	Total hazard Index:	8×10^{-5}
RECREATIONAL USERS - Children		
Beryllium		1.6×10^{-4}
Methylene chloride		4.3×10^{-7}
Tetrachloroethene		3.3×10^{-5}
	Total hazard Index:	2×10^{-4}

carcinogenic risks for all receptors. For non-carcinogenic risks, hazard indices for all receptors are summarized in Table 5.4.

5.3 CALCULATION OF REMEDIAL GOALS

Final and proposed Maximum Contaminant Levels (MCLs) were applied as remedial goals for ground water and drinking water. Health-based remedial goals were estimated assuming that ground water is used as a source of drinking water. A second set of remedial goals was estimated for the impact of groundwater discharge to Brandywine Creek. Ambient Water Quality Criteria were also considered for the creek goals, but were not used because they are less stringent than health-based goals. Health-based remedial goals were estimated for contaminants of concern in soils and sediments.

Appropriate exposure assumptions from the risk assessment were used to estimate health-based remedial goals. Remedial goals were estimated such that residual concentrations of carcinogens will not pose a potential carcinogenic risk greater than 10^{-5}, which is the mid-point of the range considered acceptable by EPA (10^{-6} to 10^{-4}). The small receptor populations, remoteness of the site, and lack of demonstrated impacts of contamination at the site on Brandywine Creek all support a risk goal of 10^{-5}. The remedial goals are summarized in Table 5.5.

Table 5.5. Remediation goals for constituents of concern in groundwater and soil.

Constituent	For Drinking Water (µg/L)	To Impact the Creek (µg/L)
GROUNDWATER		
Benzene	5 (a)	5,000
α-BHC	0.013 (d)	13
Carbon tetrachloride	5 (a)	5,000
t-1,2-Dichloroethene	100 (b)	100,000
Methylene chloride	5 (c)	5,000
1,1,2,2-Tetrachloroethane	0.4 (d)	400
Tetrachloroethene	5 (b)	5,000
1,1,2-Trichloroethane	5 (c)	5,000
Trichloroethene	5 (a)	5,000
Vinyl chloride	2 (a)	2,000

(a) MCL, EPA (1989d)
(b) MCL, EPA (1989e)
(c) MCL, EPA (1990c)
(d) Health-based remediation goal at 10^{-6} risk.

Constituent	Remediation Goal (mg/kg)
SOIL	
Beryllium	0.86
PAHs (Benzo[a]pyrene)	0.79

6 CORRECTIVE MEASURES

The risk assessment (Section 5) identified remedial goals for PAHs in soil and for VOCs in groundwater. The concern for PAHs in soil is based on worker exposure. The concern for groundwater is its impact on Brandywine Creek. If groundwater below the site were to be used for drinking water, the groundwater itself would be a concern.

Corrective measures have been developed to achieve the remedial goals. These measures, the rationale for selection, performance expectations, and monitoring requirements are presented in the remainder of this section.

6.1 DESCRIPTION OF CORRECTIVE MEASURES

The Corrective Measure Program consists of the following:

1. Soils -- to address PAH contamination, excavation protocols will be developed to minimize worker exposure.

2. Groundwater -- to address potential adverse impact of groundwater discharge to Brandywine Creek, a monitoring plan will be implemented and a remedial contingency plan will be developed. To address the very unlikely use of the groundwater for drinking, deed restrictions will be recorded.

3. Surface water and creek sediments -- no action is required.

6.1.1 Soils Plan

The purpose of the soils plan is to minimize worker exposure to soils containing PAHs above remedial goals. This will be accomplished by including additional protocols for excavation activities in the site area. DuPont already has an established excavation protocol and a permit process that achieve many of the goals necessary to prevent worker exposure. The existing protocols and permit process will be reviewed and modified as necessary. Because PAH contaminated fill occurs in several locations in the study area, the protocols will apply throughout the study area.

For future use as a residential area, the risk assessment indicated that no remedial action was required because of limited potential exposure.

6.1.2 Groundwater

The groundwater plan consists of monitoring activities and the development of remedial contingency plan. The contingency plan will describe the implementation procedures for a pump-and-treat program and a pilot soil vapor extraction system. If the contingent programs become necessary they will be installed and operated.

Groundwater monitoring will be done at existing wells on site for an initial period of five years. After five years the need for continued monitoring will be reassessed. The monitoring activities will involve groundwater sampling, analysis of samples for volatile organic compounds (VOCs), and measurement of groundwater elevations in wells.

All existing wells will be included in the monitoring network. Wells MW-10, MW-7, MW-6, MW-9, MW-5, MW-4, MW-8, MW-3A, and MW-3B will be used as compliance point wells. Monitoring will be conducted quarterly for the first year, semi-annually for the next three years, and annually thereafter. At year five, the schedule and need for monitoring will be reviewed by DuPont and recommendations will be submitted to EPA for review and approval.

The remedial goals for impact on Brandywine Creek will be used as action levels in the following manner. The results of the VOC analyses for each of the constituents of concern will be averaged for the nine compliance wells. Should the average concentration exceed 40% of a remedial goal or should any single analysis exceed 200% of a remedial goal a retest will be conducted within 30 days after receipt of the analysis. If the goals are still exceeded, the remedial contingency plan will be implemented.

The contingent groundwater remedy is expected to involve pumping from wells MW-3B, MW-8, and MW-2B as shown in Figure 6.1. If these wells are deemed unsuitable as recovery wells, new wells in the same areas will be constructed and used. In the unlikely event that any

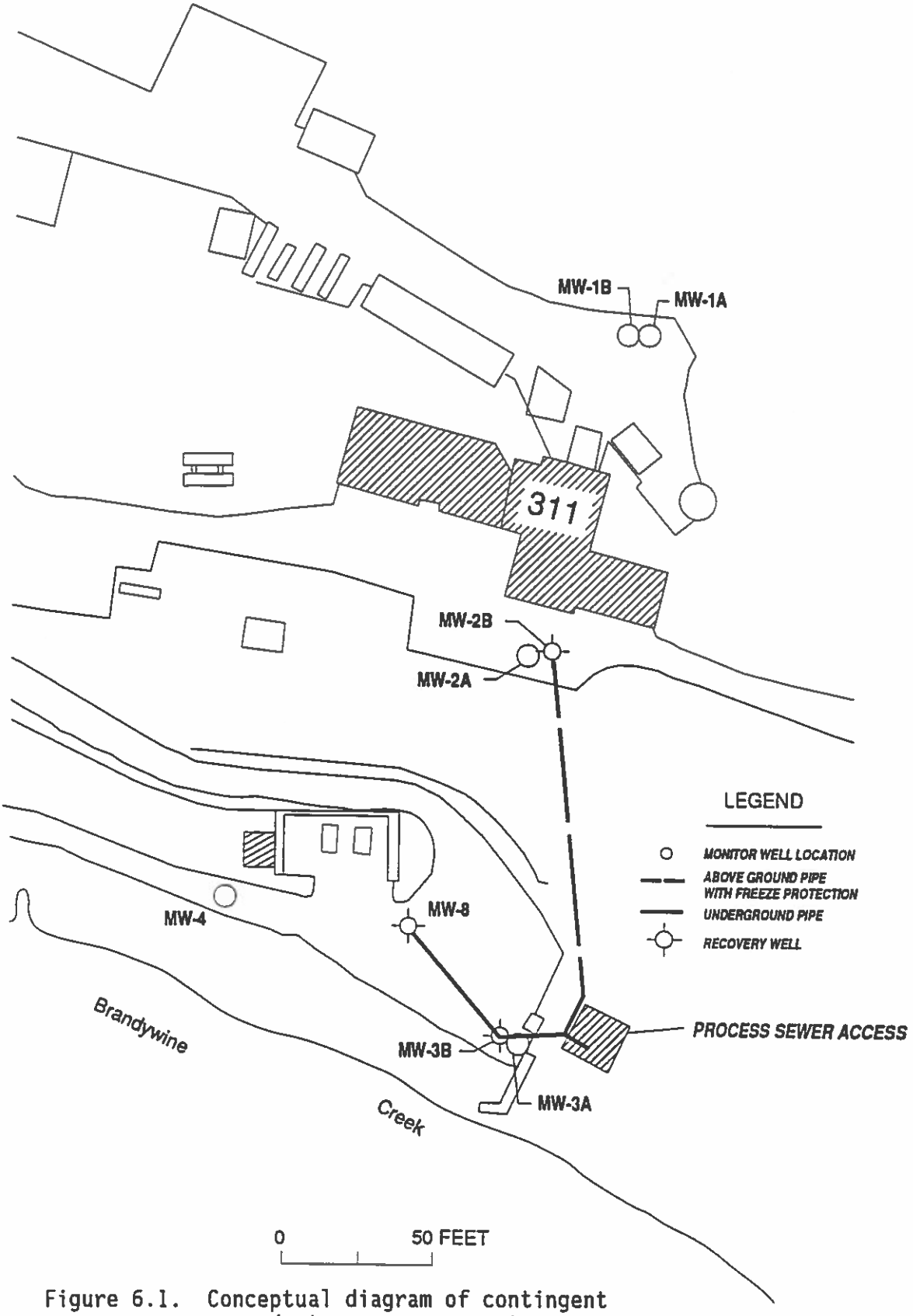

Figure 6.1. Conceptual diagram of contingent groundwater recovery system.

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A7624-001/QA/4

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EXPERIMENTAL STATION, WILMINGTON, DE

other well exceeds 10% of a remedial goal, it will be added to the recovery network. Groundwater will be pumped continuously to the process sewer to the east of well MW-3A. Precautions to prevent freezing in the pipeline will be taken.

The combined pumping rate of the three wells is anticipated to be less than 10 gpm. The expected concentrations of total VOCs would be on the order of 5 to 10 ppm if the contingent remedy is implemented. Recovery of groundwater would continue until the chemical concentration of discharge to the sewer was reduced below all remedial goals for impact to the creek.

A second approach to remediating groundwater involves removal of volatiles in soil to reduce leaching to groundwater. This is often accomplished by soil vapor extraction. Soil vapor extraction is dependent on site conditions. Because of the generally low concentrations measured in soil gas during the RFI (well below one mg/L) soil vapor extraction is expected to be marginally successful, at best. A prototype soil vapor extraction system will be constructed and operated should the contingent remedy become necessary. The conceptual prototype system is illustrated in Figure 6.2. Based on a five-day test of the prototype system, a full scale system will be designed, constructed, and operated. The full scale system will be designed to address volatiles in the area indicated in Figure 6.3. If the full scale system is feasible, it will be operated until contaminant mass removal rates are reduced to 5% of the initial rates or some other fixed rate determined in the design stage.

6.2 RATIONALE FOR APPROACH

The remedial approach was designed to meet appropriate remedial goals based on risk to public health and the environment.

For soils the concern was PAH constituents. The remedial goals were exceeded in only four locations. At each location, worker exposure was not possible due to pavement or clean fill above the contaminated zones. Removal of soil or capping would be appropriate actions if remedial goals were exceeded in soil at the surface.

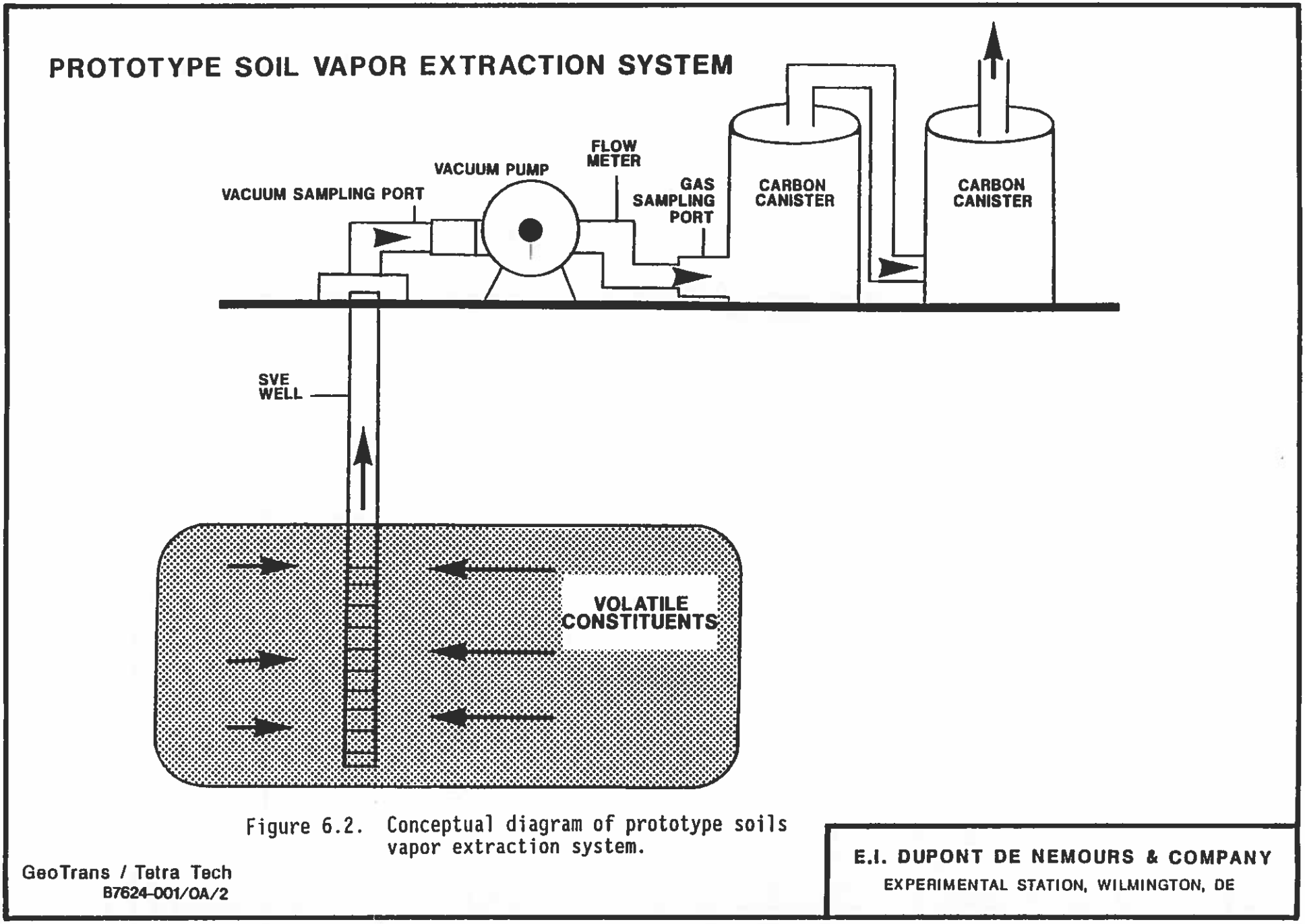

Figure 6.2. Conceptual diagram of prototype soils vapor extraction system.

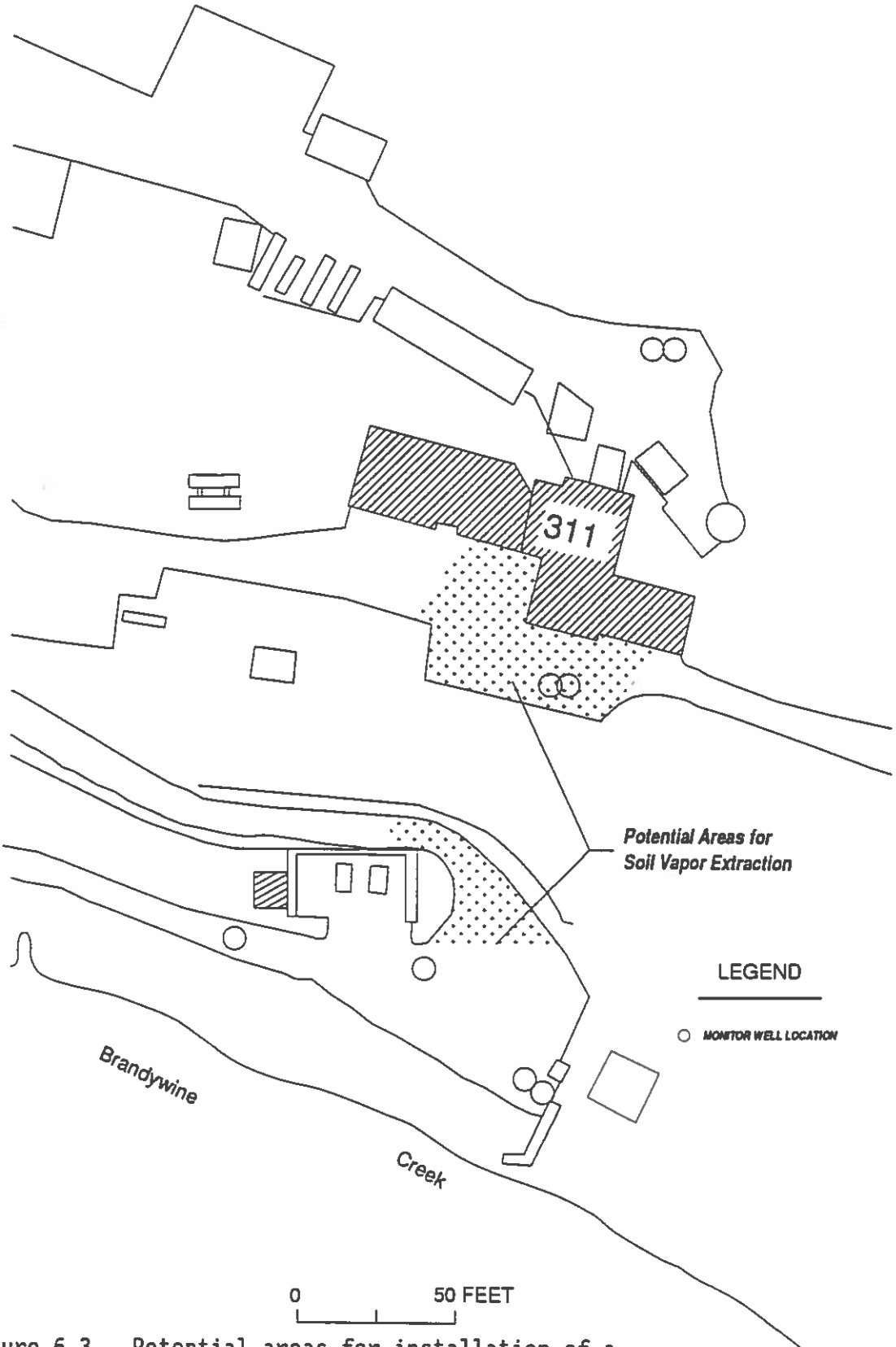

Figure 6.3. Potential areas for installation of a soil vapor extraction system.

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Because surface soil samples were below goals, excavation protocols are the only measure deemed necessary.

Groundwater below the site is not used for drinking water or any other purpose. Furthermore, due to the low producing, thin, and shallow nature of the ground flow zones, and the availability of public water supplies, it is extremely unlikely that groundwater below the site could or would be used for drinking water. To address the remedial goals for groundwater as drinking water, no action is necessary as long as DuPont maintains control of the facility. Deed restrictions and monitoring well grouting would be appropriate if DuPont were ever to sell the site.

Groundwater discharge to Brandywine Creek is not affecting surface water quality. Concentrations of volatile organic compounds in groundwater are below remedial goals for impact on the creek, but a few wells have concentrations greater than 10% of some remedial goals. Therefore, a monitoring program with a contingent remedy is necessary. Pumping with treatment is the most feasible approach to reduce groundwater contamination levels. Because public treatment is available through the nearby process sewer, no treatment facility is needed.

In addition to the pump-and-treat contingent remedy, a prototype soil vapor extraction test would be conducted should remedial goals for discharge to the creek be exceeded. A prototype is planned because the feasibility of soil vapor extraction at the site is not now known. If it is feasible, a full scale system would be designed, constructed, and implemented to reduce leaching of volatile organic compounds to groundwater.

6.3 SCHEDULE

The excavation protocols, the monitoring plan, and the remedial contingency plan will be developed within 60 days of approval of the Corrective Measures Study. The contingency remedies will be designed so that they can be constructed and implemented within 90 days of a determination to proceed.

7 DESIGN AND IMPLEMENTATION PRECAUTIONS

No significant problems or difficulties are anticipated in implementing the planned corrective measures. The plan involves monitoring, the design of contingent remedies, and the construction and operation of the contingent remedies if they become necessary. Groundwater monitoring and pump-and-treat remedies are straightforward. Because groundwater would be discharged to the process sewer for treatment, the design and operation is further simplified.

Additional engineering data is required for implementation of a full scale soil vapor extraction system. However, the prototype system will provide that data.

State permits will be required for new wells, DuPont's existing sewer permit with New Castle County Department of Public Works will need to be modified to accommodate groundwater pumping. Construction permits from DuPont will be required for any excavation, construction, or well drilling activities.

No access, easements, or right of way problems are anticipated because the site is on property controlled by DuPont.

A health and safety plan will be developed for monitoring and contingent remedial construction activities. Given the scope of the potential remedies, the health and safety plan is expected to be similar to the one approved and used for the RFI.

A community relations plan will be developed. A community relations contact at the site will be identified. The RFI and CMS documents will be made available for inspection by the public on site. Notification of the corrective measure plan will be announced in the local newspaper and public comments solicited. Response to public comments will be provided.

8 COSTS

The cost estimates provided here were developed based on discussions with vendors and on experience in performing work of similar scope. The costs do not include DuPont's cost to manage the work.

8.1 EXCAVATION PROTOCOLS

The development of heath and safety protocols for excavation in the site area is a one time cost of $8,000. Annual review of the protocols is a recurrent cost of $600.

8.2 GROUNDWATER MONITORING COSTS

The groundwater monitoring costs will vary for the first four years as the frequency of the sampling changes. Therefore, the first five years of groundwater monitoring are considered a capital cost. Annual monitoring subsequent to year five is considered a recurrent cost. Monitoring costs are summarized in Table 8.1.

8.3 CONTINGENT GROUNDWATER PUMP-AND-TREAT SYSTEM

The cost estimates here are based on an assumed flow rate of 10 gpm. This flow rate is a high estimate of the flow in the area of the recovery system. Actual sustainable rates could vary from 2 to 10 gpm. The costs are summarized in Table 8.2.

8.4 PROTOTYPE SOIL VAPOR EXTRACTION SYSTEM

The prototype soil vapor extraction system is a one time cost that will occur if action levels are exceeded. No costs can be developed for a full scale system because it is not known if one will be feasible. The costs are given in Table 8.3.

Table 8.1. Groundwater monitoring cost estimate.

	Capital One Time	O&M
Develop Monitoring Plan	$ 8,000	
Develop Contingency Remedial Plan	$ 20,000	
Year 1		
64 samples VOC analysis @ 300	$ 19,200	
Sample collection and reporting man days 32 @ 500	$ 16,000	
Data validation at 10% analysis cost	$ 1,920	
Year 3 - 4		
96 samples VOC analysis @ 300	$ 28,800	
Sample collection and reporting 48 man days @ 500	$ 24,000	
Data validation @ 10% analysis cost	$ 2,880	
Year 5 (O&M after year 5)		
16 samples VOC analysis @ 300	$ 4,800	$ 4,800
Sample collection and reporting 6 man days @ 500	$ 3,000	$ 3,000
Data validation @ 10% analysis cost	$ 480	$ 480
Total	$129,080	$ 7,680

Table 8.2. Cost estimate for contingent pump-and-treat remedy.

	Capital One Time	O&M
Well installation 3 wells @ $9,000	$27,000	
Pumps and Installation 3 @ $1,500	$ 4,500	
Trench and Pipeline 250 feet @ 40/ft	$10,000	
Controls Equipment & Shed	$10,000	
Engineering Design	$ 6,000	
Contingency	$15,000	
Fees to Sewer Authority	$ 5,000	
Maintenance and Reporting 52 days @ $500		$26,000
Power 12 months @ $120/month		$ 1,440
Sampling & Analysis (VOCs) 15 samples @ $300		$ 4,500
Total Costs	$77,500	$31,940

Table 8.3. Costs of prototype soil vapor extraction system.

	Capital One Time
Well installation	$ 4,000
Equipment costs	
Truck, monitoring, air filter	$ 3,000
Computer	$ 500
Laboratory	$ 800
Mantime (field) 180 hours at 60	$10,800
Design final program 120 hours at 70	$ 8,400
Contingency	$ 5,000
Total	$32,500

APPENDIX 1

Risk Assessment and Estimation of Remediation Goals

RISK ASSESSMENT AND

ESTIMATION OF REMEDIATION GOALS

for the

DuPONT EXPERIMENTAL STATION SITE

June 21, 1991

Prepared for:

E.I. du Pont de Nemours & Co., Inc.
Wilmington, DE

For Submission to:

U.S. EPA Region III
Philadelphia, PA

Prepared by:

Karch & Associates, Inc.
1701 K Street N.W., Suite 1000
Washington, DC 20006

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I. INTRODUCTION

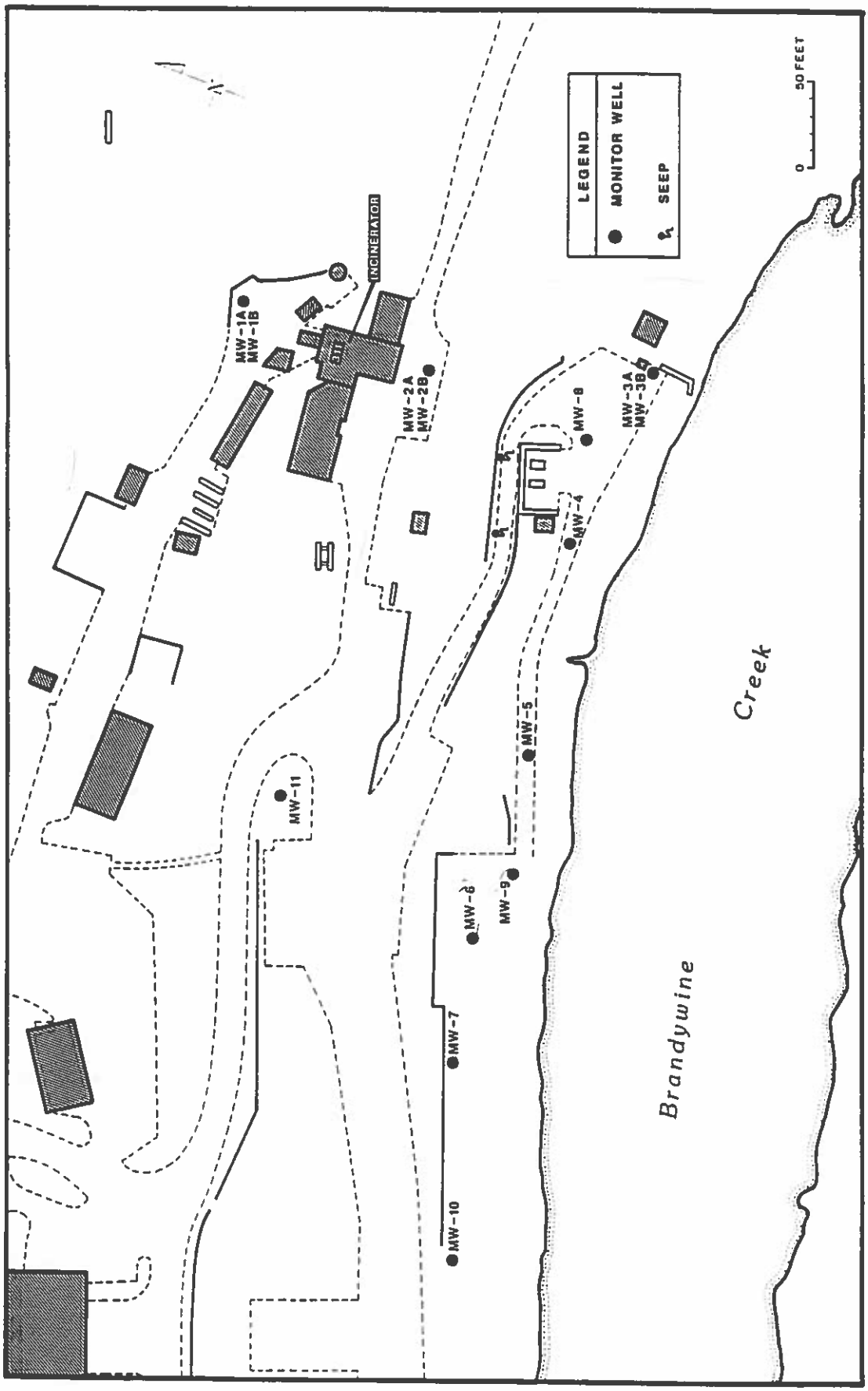
This report, prepared by Karch & Associates, Inc. as part of a Corrective Measures Study directed by GeoTrans, Inc., presents results of a human health risk assessment for the Experimental Station Site operated by E.I. du Pont de Nemours & Co., Inc. in Wilmington, Delaware. Also included in this report are remediation goals established for the constituents of concern at this site. Remediation goals are estimates of residual constituent concentrations that will not pose unacceptable risks to human health and the environment. Remediation goals are used to evaluate alternative cleanup options for the site and may or may not be used as final cleanup standards should any remediation be performed at this site.

The proposed Corrective Action Rule (EPA 1990a) identifies circumstances under which a Corrective Measures Study (CMS) must be performed at a solid waste management unit (SWMU) at a Hazardous Waste Management Facility. The proposed rule defines requirements for conducting remediation investigations, evaluating potential remedies, and selecting and implementing remedies at RCRA facilities. As part of this process, a CMS may be required if constituents at the site are found in environmental media at concentrations above the Action Levels specified in the proposed rule. As part of the CMS, health-based remediation goals can be estimated using realistic and site-specific exposure scenarios. Remedial alternatives are then evaluated in terms of their ability to achieve these remediation goals and other criteria.

The general layout of the portion of the Experimental Station covered by the RCRA Facility Investigation, which is situated along the banks of Brandywine Creek, is shown in Figure 1. The Experimental Station is the main research and development facility for DuPont and has been the site of active research for approximately 90 years. Currently, about 5,000 chemists, engineers and technicians dedicated to product development and

Figure 1. Experimental Station Site Plan

Source: GeoTrans (1990).



basic research are employed at the site. The remediation site is surrounded by the Brandywine Creek and additional property owned and controlled by DuPont (GeoTrans 1990).

This report presents the results of a human health risk assessment and comprises the following sections:

- Identification of constituents of concern.
- Human-health risk assessment for constituents of concern.
- Calculation of health-based remediation goals for those constituents in media associated with elevated risks in the risk assessment.
- Estimation and selection of remediation goals for the site.

II. CONSTITUENTS OF CONCERN

A. Identification of Action Levels

Action levels in soils, air, and water for several compounds are listed in Appendix A of the proposed Corrective Action Rule (EPA 1990a). Under the proposed rule, exceeding these action levels may trigger the need to perform a Corrective Measures Study. In the EPA policy for corrective action, these action levels are considered to be screening concentrations and are not necessarily intended for use as remediation goals. Karch & Associates, Inc. used these action levels as a first screen for identifying constituents of concern at the Experimental Station site. We chose appropriate screening concentrations for all constituents on the following basis:

- Action levels listed in the proposed Corrective Action rule (EPA 1990a) were selected as appropriate screening concentrations for constituents in soils, sediments, and ground water (if no MCL exists).
- Final and proposed MCLs were selected as appropriate screening levels for constituents detected in surface and ground water because MCLs take precedence over

action levels listed in Appendix A of the proposed Corrective Action rule (EPA 1990a).

- If no action level was listed in the Corrective Action rule, screening levels were estimated using the formulae in Appendix E (EPA 1990a).

Screening levels for the constituents detected at the Experimental Station are summarized in Tables below.

B. Selection of Constituents of Concern

Constituents of concern were selected in each environmental medium by comparing the maximum detected concentration of each constituent to the screening level for that constituent. Concentration data for all constituents were obtained from the RCRA Facility Investigation conducted for the Experimental Station site by GeoTrans, Inc. (1990).

A constituent with a maximum detected concentration greater than our screening level in a given medium was identified as a constituent of concern, unless one of the following applied:

- For metals without action levels, the maximum detected concentration did not exceed normal background concentrations (e.g., vanadium in soils).
- The constituent was detected in blank samples and was therefore considered to be a lab contaminant (e.g. bis-2-ethylhexylphthalate in ground water).
- The constituent was detected in only one sample in that medium (e.g., aldrin in ground water).
- The constituent was eliminated if lack of toxicity data prevented quantitative risk assessment (e.g., copper in soils).
- When no action level was available and sufficient data were not available to calculate a screening level (e.g., m-dichlorobenzene), the maximum detected concentration was compared to the action level for a closely related constituent (e.g., ortho- and para-dichlorobenzene).

Tables 1 through 5 detail the comparison of maximum detected concentrations of all compounds found at the DuPont site to our screening levels by specific medium. Although biphenyl and biphenyl oxide were believed to be present in potentially harmful concentrations, the observed concentrations of these compounds were much lower than the screening levels we estimated following Appendix E of the Corrective Action rule (EPA 1990a). The constituents of concern selected for this risk assessment are summarized in Table 6. At the request of EPA Region III, trichloroethene and methylene chloride were also added as constituents of concern in soils despite the fact that neither compound was detected at concentrations exceeding our screening levels.

III. HUMAN HEALTH RISK ASSESSMENT FOR CONSTITUENTS OF CONCERN

Karch & Associates, Inc. consulted guidance materials for the Superfund program for the purposes of performing the risk assessment. Although the Experimental Station is not a Superfund site, we followed Superfund guidance documents because these materials constitute the Agency's standard for risk assessment. In addition, the proposed rule for corrective action (EPA 1990a) stated an objective of enhancing comparability of remedial actions under Superfund and RCRA. Among the materials consulted were the Risk Assessment Guidelines for Superfund (RAGS) (EPA 1989a), the Superfund Exposure Assessment Manual (SEAM) (EPA 1988), the Superfund Public Health Evaluation Manual (SPHEM) (EPA 1986) and the Exposure Factors Handbook (EPA 1989b). Following the most recent EPA policy, we have developed a reasonable maximum exposure estimate of risk for the Experimental Station site. RAGS defines the concept of a reasonable maximum exposure (RME) estimate as the "highest exposure that is reasonably expected to occur at a site" (EPA 1989a). All assumed values for exposure variables used in the risk assessment calculations were derived from recommendations in RAGS (EPA 1989a).

Table 1. Maximum Concentrations and Screening Levels for Organic Constituents Detected in Soils (µg/kg)[1]

Constituent	Maximum Value	Screening Level[2]
Acetone	94 B	8,000,000
Biphenyl/ Biphenyl oxide	120 J	4,000,000[3]
Carbon disulfide	1 J*	8,000,000
Chloroform	34	100,000
1,1-Dichloroethene	240 J*	8,000
t-1,2-Dichloroethene	4,000	1,600,000[3]
Ethylbenzene	190 J*	8,000,000
@Methylene chloride	720 B	90,000
@PAHs (e.g., Benzo[a]pyrene)	46,960	60[3]
@Tetrachloroethene	13,000	10,000
Toluene	290 B	20,000,000
1,1,1-Trichloroethane	55	700,000
1,1,2-Trichloroethane	160 J*	100,000
@Trichloroethene	30,000	60,000
Xylenes	1 J*	200,000,000

"@" indicates selected constituent of concern.
"J" denotes estimated values.
"B" denotes constituents present in blank samples.
"*" indicates constituents detected in only one sample.

[1]Only constituents found above detection limits are included.
[2]EPA (1990a), Appendix A, unless otherwise noted.
[3]Derived according to formulae in EPA (1990a), Appendix E.

Table 2. Maximum Concentrations and Screening Levels for Metals Detected in Soils (mg/kg)[1]

Metal	Maximum Value	Background Range[2]	Screening Level[3]
Arsenic	18.4	1.0 – 40	80
Barium	154	100 – 3500	4000
@Beryllium	0.41	0.1 – 40	0.2
Cadmium	3.8	0.01 – 7.0	40
Chromium	49.4	5 – 3000	400
Cobalt	19	1.0 – 40	—
Copper	173	2.0 – 100	—
Lead	73.5	2.0 – 200	500[4]
Mercury	3	0.01 – 0.08	20
Nickel	30.1	5 – 1000	2,000
Selenium	0.68	0.1 – 2.0	—
Silver	2.21	0.1 – 5.0	200
Vanadium	57.3	20 – 500	—
Zinc	165	10 – 300	16,000[5]

"@" indicates selected constituent of concern.

[1]Only constituents found above detection limits are included.
[2]Dragun 1988.
[3]EPA 1990a, Appendix A, unless otherwise noted.
[4]EPA 1989c.
[5]Derived according to formulae in EPA (1990a), Appendix E.

Table 3. Maximum Concentrations and Screening Levels of Constituents Detected in Ground Water (µg/L)[1]

Constituents	Maximum Value	Screening Level[2]
Acetone	490	4,000
Aldrin	0.04 J*	0.002
@Benzene	300	5
@α-Benzene hexachloride	0.06	0.006
Biphenyl/Biphenyl oxide	363	1,750[3]
@Carbon tetrachloride	680	5
Chlorobenzene	24	100[4]
Chloroform	42	100[5]
Di-n-butylphthalate	2 J	4,000
m-Dichlorobenzene	7 J	—
o-, p-Dichlorobenzene	11 J	75
1,1-Dichloroethane	190	0.4[3]
1,1-Dichloroethene	7	7
@t-1,2-Dichloroethene	840	100[4]
2,4-D	0.48 J*	100
Diethylphthalate	2 J	30,000
Di-n-octylphthalate	2 J*	—
Ethylbenzene	65	700[4]
bis-2-Ethylhexylphthalate	28 B	4[6]
@Methylene chloride	130	5[6]
Silvex	0.06 J*	10
@Tetrachloroethene	530	5[4]
@1,1,2,2-Tetrachloroethane	5,100	2
Toluene	250	2,000[4]
1,1,1-Trichloroethane	10 J	200
@1,1,2-Trichloroethane	130	5[6]
@Trichloroethene	7,700	5
@Vinyl chloride	610	2
Xylenes	38	10,000[4]
Lead	3.75 B	50

"@" indicates selected constituents of concern.
"J" denotes estimated values.
"B" denotes constituents present in blank samples.
"*" indicates constituents detected in only one sample.

[1]Only constituents found above detection limits are included.
[2]EPA 1990a, Appendices A and B, unless otherwise noted.
[3]Derived according to formulae in EPA (1990a), Appendix E.
[4]Proposed MCLs. EPA 1989d.
[5]The MCL for total trihalomethanes is 100 µg/L.
[6]Proposed MCLs. EPA 1990b.

Table 4. Maximum Concentrations and Screening Levels for Organic Constituents Detected in Sediments (µg/kg)[1]

Constituent	Maximum Value	Screening Level[2]
Biphenyl/ Biphenyl oxide	26	4,000,000[3]
t-1,2-Dichloroethene	110	1,600,000[3]
Methylene chloride	18 B*	90,000
Tetrachloroethene	240	10,000
Toluene	21	400,000
Trichloroethene	190	60,000

"@" indicates selected constituents of concern.
"B" denotes constituents present in blank samples.
"*" indicates constituents detected in only one sample.

[1]Only constituents found above detection limits are included.
[2]EPA (1990a), Appendix A, unless otherwise noted.
[3]Derived according to formulae in EPA (1990a), Appendix E.

Table 5. Maximum Concentrations and Screening Levels for Metals Detected in Sediments (mg/kg)[1]

Metal	Maximum Value	Background Range[2]	Screening Level[3]
Arsenic	4.12	1.0 – 40	80
@Beryllium	8.42	0.1 – 40	0.2
Cadmium	53.1 *	0.01 – 7.0	40
Chromium	207	5 – 3000	400
Copper	52.4	2 – 100	—
Lead	85.4	2.0 – 200	500[4]
Mercury	3.05	0.01 – 0.08	20
Nickel	42.5	5 – 1000	2,000
Zinc	396	10 – 300	16,000[5]

"@" indicates selected constituents of concern.
"*" indicates constituents detected in only one sample.

[1]Only constituents found above detection limits are included.
[2]Dragun 1988.
[3]EPA 1990a, Appendix A, unless otherwise noted.
[4]EPA 1989c.
[5]Derived according to formulae in EPA (1990a), Appendix E.

Table 6. Selected Constituents of Concern for Risk Assessment

Soil

Beryllium	Methylene chloride
PAHs (e.g., Benzo[a]pyrene)	Tetrachloroethene
Trichloroethene	

Ground Water

Benzene	α-Benzene hexachloride
Carbon tetrachloride	trans-1,2-Dichloroethene
Methylene chloride	1,1,2,2-Tetrachloroethane
Tetrachloroethene	1,1,2-Trichloroethane
Trichloroethene	Vinyl chloride

Surface Water (Brandywine Creek)

No constituents detected above detection limits

Sediments

Beryllium

A. Sources of Constituents

Figure 2 illustrates the environmental sources of constituents considered in this risk assessment. Constituents in the soil, sediment and surface water may pose potential health risks to humans. GeoTrans, Inc. (1990) has shown that the ground water moves through the contaminated soil and emerges as seep water along an onsite roadway (see Figure 2). The ground water in these "seeps" contains volatile constituents, which may be inhaled by workers in the vicinity. Volatile constituents in soil may also volatilize and pose potential risks through inhalation exposures.

B. Representative Constituent Concentrations

RAGS (EPA 1989a) suggests use of the 95th percentile upper confidence limit (UCL) on the arithmetic mean to estimate representative constituent concentrations for exposure assessments. Representative concentrations for all constituents of concern in sediments, soil and ground water were calculated from data collected during the RCRA Facility Investigation (GeoTrans 1990). Table 7 lists the representative concentrations for all constituents of concern calculated from the measured data. In calculating the mean and 95th percentile UCL concentrations, all non-detects were assigned a value equal to one-half the limit of detection. Split and duplicate samples were averaged.

For simplicity and convenience, benzo[a]pyrene was selected as a surrogate indicator for all polynuclear aromatic hydrocarbon (PAH) compounds. The complex mixture of PAHs detected in each sample can be expressed as an equivalent concentration of benzo[a]pyrene using relative carcinogenic potency factors for each PAH as compared to benzo[a]pyrene (Clement Associates 1988). Converting concentrations of individual PAHs to equivalent concentrations of benzo[a]pyrene simplifies the risk calculations and avoids the overestimates of risk that would result from treating all detected PAH concentrations as benzo[a]pyrene.

Figure 2. Constituent Sources at the Experimental Station

Source: GeoTrans, Inc.

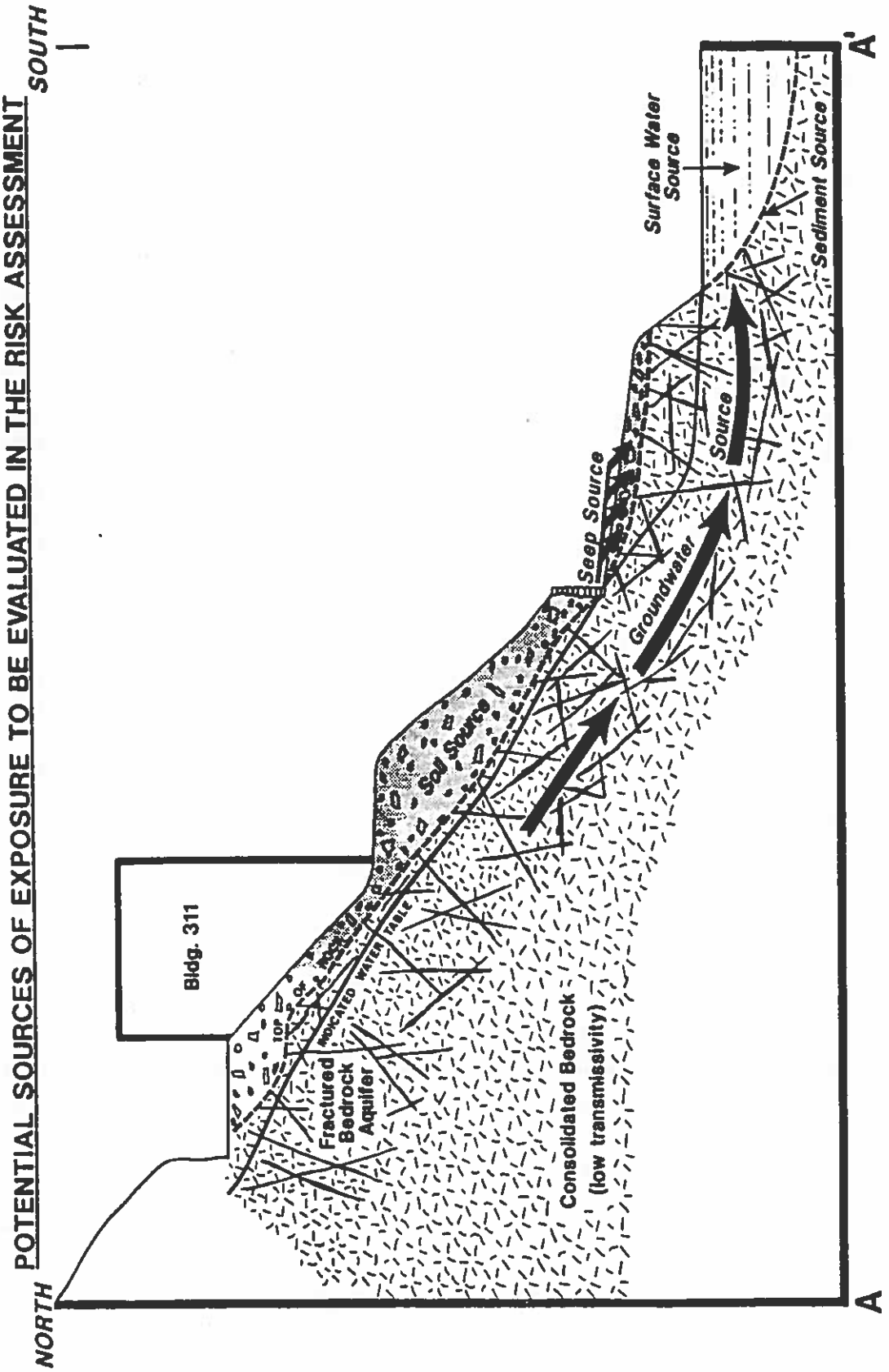


Table 7. Representative Concentrations of Constituents of Concern

Compound	Frequency of Detection	Units	Range	Mean[1]	95th UCL[1]
SOIL					
Beryllium	(2/4)	mg/kg	0.15J – 0.41	0.279	0.40
Methylene chloride	(28/32)	µg/kg	3J – 720B	48.3	85.6
PAHs (Benzo[a]pyrene)	(13/17)	µg/kg	99 – 46960	3922	8711
Tetrachloroethene	(15/32)	µg/kg	5J – 13000	420	1109
Trichloroethene	(16/32)	µg/kg	<5.3 – 30000	967.6	2557
SEDIMENT					
Beryllium	(2/5)	mg/kg	0.566J – 8.42	2.02	5.43
GROUND WATER					
Benzene	(12/24)	µg/L	1J – 300	51.5	87.3
α-BHC	(2/4)	µg/L	0.05J – 0.06	0.04	0.06
Carbon tetrachloride	(2/17)	µg/L	<5 – 680	62.2	138
trans-1,2-Dichloroethene	(12/21)	µg/L	4J – 840	211	319
Methylene chloride	(15/28)	µg/L	2J – 130	8.66	16.4
1,1,2,2-Tetrachloroethane	(16/17)	µg/L	4J – 5100	428	790
Tetrachloroethene	(19/26)	µg/L	4J – 530	69.7	113
1,1,2-Trichloroethane	(2/18)	µg/L	<5 – 130	12	24.9
Trichloroethene	(20/27)	µg/L	3J – 7700	553	1090
Vinyl chloride	(9/22)	µg/L	3J – 610	69.7	125

[1]For calculations of the mean and 95th percentile upper confidence limit on the mean, all non-detects were assigned a value equal to one-half of the limit of detection.

"J" indicates an estimated concentration that is below the limit of detection for that chemical.
"B" indicates constituents present in blank samples.
"<" indicates a non-detect at the given limit of detection.

Table 8 lists the relative potency factors for the various PAHs. Appendix 1 illustrates the calculations of the benzo[a]pyrene-equivalent concentrations for the soil samples. Although the Clement (1988) report does not represent final Agency policy, we believe use of the relative potency estimates is appropriate because:

- use of the comparative potency approach allows us to include most of the PAHs in the risk assessment calculations explicitly (EPA has estimated a cancer potency factor only for benzo[a]pyrene);
- the comparative potency approach avoids the obvious gross overestimates that would result from assuming that all carcinogenic PAHs have the same carcinogenic potential as benzo[a]pyrene; and
- the Agency currently endorses a similar method (Toxicity Equivalent Factors) for treating mixtures of chlorinated dibenzodioxins and dibenzofurans (EPA 1989e).

Volatilization of organic constituents from the soil and the groundwater seeps may be a source of potential exposure onsite. However, no appropriate data were available to estimate representative concentrations of volatilized organic constituents. Therefore, the volatilization process from these two sources was modeled using appropriate mathematical models and assumptions. The formulae and assumptions used in the models are summarized in Appendix 2.

Vapor concentrations of constituents volatilizing from soil were estimated using the 95th percentile UCL concentration of those constituents in soil. Table 9 summarizes the estimated average concentrations of volatile constituents emanating from soil.

GeoTrans, Inc. (1990) demonstrated that the ground water appearing in the seeps is hydraulically connected to the water in Monitoring Well 2A. Only seven of the ten constituents of concern identified in ground water were detected in MW-2A. Therefore, only those constituents of concern detected in MW-2A were included in the inhalation calculations. Due to the lack of

Table 8. Relative Potency Estimates for PAHs

Source: Clement Associates (1988).

Compound	Relative Potency Factor
Anthracene	E
Benz[a]anthracene	0.145
Benzo[a]pyrene	1.0
Benzo[b]fluoranthene	0.140
Benzo[k]fluoranthene	0.066
Benzo[g,h,i]perylene	0.022
Chrysene	0.0044
Fluoranthene	D
Fluorene	D
Indeno[1,2,3-cd]pyrene	0.232
Phenanthrene	D
Pyrene	0.081

Carcinogenicity classifications from EPA (1985):

D Not classified as to carcinogenicity.
E No evidence for human carcinogenicity.

Table 9. Estimated Concentrations of Volatilized Constituents

a. Constituents Volatilizing from Soils

Constituent	Representative Concentration in Soil ($\mu g/kg$)	Estimated Volatilized Concentration ($\mu g/m^3$)
Methylene chloride	85.6	0.000039
PAHs (Benzo[a]pyrene)	8711	2.9×10^{-13}
Tetrachloroethene	1109	0.000074
Trichloroethene	2557	0.00036

b. Constituents Volatilizing from Groundwater Seeps

Constituent	Maximum Concentration in Seep[1] ($\mu g/L$)	Estimated Volatilized Concentration ($\mu g/m^3$)
Benzene	270	0.013
trans-1,2-Dichloroethene	840	0.035
Methylene chloride	21	0.00093
1,1,2,2-Tetrachloroethane	130	0.0037
Tetrachloroethene	52	0.0017
Trichloroethene	70	0.0025
Vinyl chloride	410	0.022

[1]The concentrations of constituents in the seep were conservatively assumed to be approximated by the maximum constituent concentration detected in Monitoring Well 2A during two rounds of sampling. Concentration data were taken from GeoTrans (1990).

concentration data in the seep water, the maximum constituent concentrations detected in MW-2A were used to estimate vapor concentrations of volatiles emanating from the seep. Use of maximum concentrations results in a conservative overestimate of average concentrations of volatilized constituents. The estimated average concentrations of volatile constituents emanating from the groundwater seeps are listed in Table 9.

C. Exposure Pathways

Two classes of exposure scenarios were originally postulated for this risk assessment: (1) current industrial use and (2) potential future recreational use of the site. The site is currently operated by DuPont and access is strictly limited to employees. Due to the long history of industrial use at this site, it is unlikely that this site will ever be used for recreational activities. The terrain at the site virtually rules out future residential use. In order to perform a conservative risk assessment, we assumed future recreational use of the site by adults and children. In addition, area residents downstream from the site who take drinking water from Brandywine Creek could potentially be exposed to constituents in the creek. No constituents of concern were detected in Brandywine Creek, however (GeoTrans 1990). Table 10 lists the potential exposure pathways for each group of receptors associated with the site.

D. Estimates of Exposures

Exposures to constituents are expressed in terms of "intakes" on a basis of milligram of constituent per kilogram body weight per day (mg/kg/day). For carcinogens, intakes are averaged over the entire life of the receptors; whereas for non-carcinogens, intakes are averaged only over the duration of exposure. This difference is necessitated by the manner in which EPA evaluates toxicity data and expresses toxicity constants for carcinogenic and non-carcinogenic constituents. Intakes of non-carcinogens are termed "Average Daily Doses" or ADDS, and intakes of carcinogens are termed "Lifetime Average Daily Doses" or LADDs.

Table 10. Exposure Scenarios at the Experimental Station Site

Industrial Workers (Current Use)
Dermal contact with soil
Inadvertent ingestion of soil
Inhalation of volatilized VOCs from soil
Inhalation of volatilized VOCs from seep water
Recreational Users (Future Use)
* Dermal exposure to surface water while swimming
* Ingestion of surface water while swimming
Dermal contact with sediments in Brandywine Creek
Dermal contact with soil
Inadvertent ingestion of soil
Inhalation of volatilized VOCs from seep water
Inhalation of volatilized VOCs from soil
Area Residents (Current and Future Use)
* Ingestion of drinking water from Brandywine Creek

* An asterisk indicates a pathway that was considered; however, because no constituents were found at detectable levels, risks could not be estimated.

The formulae and exposure assumptions used to estimate exposures to all receptors are discussed in the sections below. Table 11 lists the assumed values for exposure variables used in each formula.

1. Inhalation of Volatilized Constituents

For inhalation of constituents emanating from the soil and groundwater seeps, estimated intakes were calculated using the following EPA-recommended formula (EPA 1989a):

$$\text{Inhalation Intake (mg/kg/day)} = \frac{(CA)(IR)(CF)(EF)(ED)}{(BW)(AT)}$$

where:

CA	Constituent concentration in air ($\mu g/m^3$),
IR	Inhalation rate (m^3/d),
CF	Conversion factor (10^{-3} mg/μg),
EF	Exposure frequency (d/yr),
ED	Exposure duration (yr),
BW	Body weight (kg), and
AT	Period over which exposure is averaged (days).

Assumed values for exposure variables are listed in Table 11. Lifetime average daily doses (LADDs) for all constituents via the inhalation exposure route for industrial and recreational receptors are summarized in Table 12. Note that ADDs were not calculated for inhalation exposures because no reference doses for this route of exposure to non-carcinogens are available. Therefore, non-carcinogenic hazards could not be evaluated for inhalation exposures.

2. Dermal Contact with Soil and Sediments

For dermal contact with soils or sediments, estimated intakes were calculated using the following formula recommended by EPA (1989a):

$$\text{Dermal Intake (mg/kg/day)} = \frac{(CS)(CF)(SA)(AF)(ABS)(EF)(ED)}{(BW)(AT)}$$

Table 11. Assumed Values for Exposure Variables Used in the Risk Assessment

Variable	Assumed Value	Reference
Body Weight	Adults – 70 kg	EPA 1989a
	Children – 16 kg	EPA 1989a
Exposure Frequency	Industrial – 8 hr/d, 250 d/yr	Standard
	Adults – 2.6 hr/d, 7 d/yr	EPA 1989a
	Children – 2.6 hr/d, 7 d/yr	EPA 1989a
Exposure Duration	Industrial – 40 yr	Standard
	Adults – 30 yr	EPA 1989a
	Children – 5 yr	EPA 1989a
Averaging Time for Exposure	Carcinogens – 70 yr	EPA 1989a
	Non-carcinogens – exposure duration	EPA 1989a
Soil Ingestion Rate	Adults – 100 mg/d	EPA 1989a
	Children – 200 mg/d	EPA 1989a
Rate of Soil and Sediment Contact	0.5 mg/cm^2	Sedman 1989
Exposed Skin Area – Sediments	Adults – 1960 cm^2	EPA 1989b
	Children – 909 cm^2	EPA 1989b
Exposed Skin Area – Soils	Industrial – 1925 cm^2	Schaum 1984
	Adults – 4050 cm^2	EPA 1989b
	Children – 3650 cm^2	EPA 1989b
Relative Dermal Absorption Fraction	Beryllium – 0.20	ATSDR 1988
	Tetrachloroethene – 0.12	Hawley 1985
	PAHs – 0.05	ATSDR 1990
Inhalation Rate	Industrial – 10 m^3/8-hr day	Leung et al. 1988
	Adults – 1.4 m^3/hr	EPA 1989b
	Children – 1.3 m^3/hr	EPA 1989b

Table 12. Lifetime Average Daily Doses (LADDs) for All Receptors: Inhalation Exposures

Constituent	Inhalation of Volatiles from Seep (mg/kg/d)	Inhalation of Volatiles from Soil (mg/kg/d)
INDUSTRIAL WORKERS		
Benzene	7.3×10^{-7}	—
Methylene chloride	5.2×10^{-8}	2.2×10^{-9}
PAHs	—	1.6×10^{-17}
1,1,2,2-Tetrachloroethane	2.1×10^{-7}	—
Tetrachloroethene	9.5×10^{-8}	4.1×10^{-9}
Trichloroethene	1.4×10^{-7}	2.0×10^{-8}
Vinyl chloride	1.2×10^{-6}	—
RECREATIONAL USERS – Adults		
Benzene	5.6×10^{-9}	—
Methylene chloride	4.0×10^{-10}	1.7×10^{-11}
PAHs	—	1.2×10^{-19}
1,1,2,2-Tetrachloroethane	1.6×10^{-9}	—
Tetrachloroethene	7.3×10^{-10}	3.2×10^{-11}
Trichloroethene	1.1×10^{-9}	1.5×10^{-10}
Vinyl chloride	9.4×10^{-9}	—
RECREATIONAL USERS – Children		
Benzene	3.8×10^{-9}	—
Methylene chloride	2.7×10^{-10}	1.1×10^{-11}
PAHs	—	8.4×10^{-20}
1,1,2,2-Tetrachloroethane	1.1×10^{-9}	—
Tetrachloroethene	4.9×10^{-10}	2.1×10^{-11}
Trichloroethene	7.2×10^{-10}	1.0×10^{-10}
Vinyl chloride	6.4×10^{-9}	—

where:

CS	Constituent concentration in soil (mg/kg),
CF	Conversion factor (10^{-6} kg/mg),
SA	Skin surface area available for contact (cm^2/day),
AF	Soil to skin adherence factor (mg/cm^2),
ABS	Relative dermal absorption fraction,
EF	Exposure frequency (d/yr),
ED	Exposure duration (yr),
BW	Body weight (kg), and
AT	Period over which exposure is averaged (days).

Assumed values for exposure variables are listed in Table 11. Estimates of the dermal absorption of constituents via the skin relative to oral absorption rates are required for use in the above formula (EPA 1989a). Beryllium is said to be "poorly" absorbed through the skin (ATSDR 1988). Due to the lack of quantitative data, the dermal absorption fraction of beryllium was assumed to be 10 percent as a conservative estimate. Following EPA guidance (EPA 1989a), the relative dermal absorption fraction for beryllium was estimated to be 20 percent, which was calculated by dividing the dermal absorption fraction (10 percent) by an estimated oral absorption fraction of 50 percent. The dermal absorption fraction for benzo[a]pyrene is approximately 3 percent and the oral absorption fraction is 79 percent (ATSDR 1990). Therefore, the relative dermal absorption fraction for benzo[a]pyrene was estimated to be 3.8 percent, which was conservatively rounded up to 5 percent. The relative dermal absorption fraction for tetrachloroethylene was assumed to be 12 percent based on recommended values for organic chemicals by Hawley (1985). Lifetime average daily doses (LADDs) for all constituents for dermal exposures are summarized in Table 13 and average daily doses (ADDs) are summarized in Table 14.

3. Ingestion of Soil

For ingestion of soils, estimated intakes were calculated using the following formula (EPA 1989a):

$$\text{Soil Ingestion Intake (mg/kg/day)} = \frac{(CS)(IR)(CF)(FI)(EF)(ED)}{(BW)(AT)}$$

Table 13. Lifetime Average Daily Doses (LADDs) for All Receptors: Non-Inhalation Exposures

Constituent	Dermal Contact w/ Soil (mg/kg/d)	Dermal Contact w/ Sediment (mg/kg/d)	Soil Ingestion (mg/kg/d)
INDUSTRIAL WORKERS			
Beryllium	4.3×10^{-7}	—	1.1×10^{-7}
Methylene chloride	5.5×10^{-8}	—	2.4×10^{-8}
PAHs	2.3×10^{-6}	—	2.4×10^{-6}
Tetrachloroethene	7.2×10^{-7}	—	3.1×10^{-7}
Trichloroethene	1.7×10^{-6}	—	7.2×10^{-7}
RECREATIONAL USERS – Adults			
Beryllium	1.9×10^{-8}	1.3×10^{-7}	7.5×10^{-10}
Methylene chloride	2.4×10^{-9}	—	1.6×10^{-10}
PAHs	1.0×10^{-7}	—	1.6×10^{-8}
Tetrachloroethene	3.2×10^{-8}	—	2.1×10^{-9}
Trichloroethene	7.3×10^{-8}	—	4.8×10^{-9}
RECREATIONAL USERS – Children			
Beryllium	1.3×10^{-8}	4.2×10^{-8}	1.1×10^{-9}
Methylene chloride	1.6×10^{-9}	—	2.4×10^{-10}
PAHs	6.8×10^{-8}	—	2.4×10^{-8}
Tetrachloroethene	2.1×10^{-8}	—	3.0×10^{-9}
Trichloroethene	4.8×10^{-8}	—	7.0×10^{-9}

Table 14. Average Daily Doses (ADDs) for All Receptors: Non-Inhalation Exposures

Constituent	Dermal Contact w/ Soil (mg/kg/d)	Dermal Contact w/ Sediment (mg/kg/d)	Soil Ingestion (mg/kg/d)
INDUSTRIAL WORKERS			
Beryllium	7.5×10^{-7}	—	2.0×10^{-7}
Methylene chloride	9.7×10^{-8}	—	4.2×10^{-8}
Tetrachloroethene	1.3×10^{-6}	—	5.4×10^{-7}
RECREATIONAL USERS – Adults			
Beryllium	4.4×10^{-8}	2.9×10^{-7}	1.8×10^{-9}
Methylene chloride	5.7×10^{-9}	—	3.8×10^{-10}
Tetrachloroethene	7.4×10^{-8}	—	4.9×10^{-9}
RECREATIONAL USERS – Children			
Beryllium	1.8×10^{-7}	5.9×10^{-7}	1.5×10^{-8}
Methylene chloride	2.3×10^{-8}	—	3.3×10^{-9}
Tetrachloroethene	4.9×10^{-7}	—	4.3×10^{-8}

where:

CS	Constituent concentration in soil (mg/kg),
IR	Soil ingestion rate (mg/day),
CF	Conversion factor (10^{-6} kg/mg),
FI	Fraction ingested from contaminated source,
EF	Exposure frequency (d/yr),
ED	Exposure duration (yr),
BW	Body weight (kg), and
AT	Period over which exposure is averaged (days).

Assumed values for exposure variables are listed in Table 11. Values for FI, the fraction ingested from contaminated source, were estimated by the fraction of waking hours that a receptor spent on the site. Thus, the value of FI for industrial workers was assumed to be (8 hr)/(16 hr) = 0.50. Similarly, FI for recreational receptors was assumed to be (2.6 hr)/(16 hr) = 0.16. Lifetime average daily doses (LADDs) of all constituents for ingestion exposures for all receptors are summarized in Table 13. Average daily doses (ADDs) of all constituents via non-inhalation exposure routes for industrial and recreational receptors are summarized in Table 14. LADDs are averaged over the entire lifetime, whereas ADDs are averaged only over the duration of exposure. The value for AT is appropriately adjusted for each calculation.

E. Characterization of Risk

Potential exposures have been estimated using conservative assumptions that result in a reasonable estimate of the maximum exposures likely to occur for industrial workers and recreational users at the site. Both carcinogenic and non-carcinogenic risks are evaluated in this risk assessment.

Reference doses (RfDs) are normally used by EPA to express the intake of a constituent below which non-carcinogenic health effects will not be observed (EPA 1989a). RfDs for oral exposures to the constituents of concern at the Experimental Station site are listed in Table 15. RfDs for inhalation exposures are not available. Therefore, only non-inhalation exposure pathways are included in the non-carcinogenic hazard

Table 15. Toxicity Constants for Constituents of Concern at the Experimental Station Site

Constituent	Oral RfD (mg/kg/d)	Oral CPF $(mg/kg/d)^{-1}$	Inhal. CPF $(mg/kg/d)^{-1}$
Benzene	3×10^{-3} (a)	2.9×10^{-2} (b)	3.5×10^{-2} (b)
α-BHC	—	6.3 (b)	6.3 (a)
Benzo[a]pyrene	—	11.5 (c)	11.5 (c)
Beryllium	5×10^{-3} (b)	4.3 (b)	8.75 (b)
Carbon tetrachloride	7×10^{-4} (b)	1.3×10^{-1} (b)	5×10^{-5} (b)
t-1,2-Dichloroethene	2×10^{-2} (b)	—	—
Methylene chloride	6×10^{-2} (b)	7.5×10^{-3} (b)	1.7×10^{-3} (b)
1,1,2,2-Tetrachloroethane	—	0.2 (b)	0.2 (b)
Tetrachloroethene	1×10^{-2} (b)	5.1×10^{-2} (a)	3.3×10^{-3} (a)
1,1,2-Trichloroethane	4×10^{-3} (b)	5.7×10^{-2} (b)	5.7×10^{-2} (b)
Trichloroethene	—	1.1×10^{-2} (a)	—
Vinyl chloride	—	2.3 (d)	3×10^{-1} (d)

(a) Proposed Corrective Action rule (EPA 1990a).
(b) Integrated Risk Information System (EPA 1991).
(c) EPA 1986.
(d) Health Effects Assessment Summary Tables (EPA 1989f).

characterization. RfDs are usually calculated based upon toxicity observed in animal studies and are extrapolated to represent human exposures using various uncertainty factors. Conservatism is built into the estimation of RfDs.

The Hazard Index (H.I.) is the ratio of the ADD to the RfD for a given constituent:

$$H.I. = ADD / RfD$$

Following EPA guidance (EPA 1989a), the individual Hazard Indices for each constituent of concern are summed to produce a total H.I. for the site. Estimated Hazard Indices for all receptors at the Experimental Station, summarized in Table 16, were calculated using the ADDs in Table 14 and RfDs in Table 15.

A total Hazard Index below 1.0 is regarded as presenting no increased risk of adverse non-carcinogenic health effects (EPA 1989a). The low Hazard Indices shown in Table 16 indicate that there is no significant non-carcinogenic health risk associated with the levels of any of the constituents of concern at the Experimental Station. Therefore, we concluded that non-carcinogenic health effects in industrial workers and recreational users would not result due to exposure to the constituents identified at the Experimental Station site. In other words, potential non-carcinogenic health effects are not of concern at this site.

A carcinogenic potency factor (CPF) is a quantitative estimate of the carcinogenic potential of a chemical (EPA 1989a). CPFs for the constituents of concern at the Experimental Station are listed in Table 15. CPFs estimated by EPA represent the upper confidence limit of potency extrapolated to low doses in humans, and are generally based on animal bioassays conducted at much higher doses. CPFs, like RfDs, are estimated with conservatism, and may overstate the actual risk posed by a chemical, which EPA readily admits.

Table 16. Summary of Estimated Hazard Indices for All Receptors at the Experimental Station Site

Constituent	Hazard Index
INDUSTRIAL WORKERS	
Beryllium	1.9×10^{-4}
Methylene chloride	2.3×10^{-6}
Tetrachloroethene	1.8×10^{-4}
Total Hazard Index:	4×10^{-4}
RECREATIONAL USERS – Adults	
Beryllium	6.8×10^{-5}
Methylene chloride	1.0×10^{-7}
Tetrachloroethene	7.9×10^{-6}
Total Hazard Index:	8×10^{-5}
RECREATIONAL USERS – Children	
Beryllium	1.6×10^{-4}
Methylene chloride	4.3×10^{-7}
Tetrachloroethene	3.3×10^{-5}
Total Hazard Index:	2×10^{-4}

Carcinogenic risk is estimated by multiplying the LADD for a constituent by its CPF:

$$Risk = (LADD)(CPF)$$

Risks associated with exposure to each carcinogen at the site are summed to estimate the total excess carcinogenic risk presented by the constituents at the site (EPA 1989a). Estimated excess carcinogenic risks for all receptors were calculated using the LADDs in Tables 12 and 13 and are summarized in Table 17.

EPA considers carcinogenic risks in the range of 10^{-6} to 10^{-4} to be acceptable (EPA 1990c). As seen from the total estimated carcinogenic risks in Table 17, the potential risks attributable to exposures at the site range from 1×10^{-6} for children recreational users to 6×10^{-5} for industrial workers. We note that more than 99 percent of the risks estimated for all receptor groups are attributable to dermal and ingestion exposures to beryllium and PAHs only. Risks attributable to volatile organics in soils, such as tetrachloroethene, trichloroethene and methylene chloride, are generally three orders of magnitude lower than those attributable to beryllium and PAHs. Total inhalation exposures account for less than 0.75 percent of the total risk. Therefore, beryllium and PAHs are identified as the compounds that "drive" the risks.

Risks at the site are within the acceptable range for all receptor groups. However, we note that the risk estimate for industrial workers (6×10^{-5}) is near the high end of the acceptable range. Although volatiles do not contribute significantly to the overall risks at the site, the soil underneath the roadway near the seeps contains relatively high concentrations of some of these compounds. However, the pavement covering at this location makes it extremely unlikely that any appreciable exposures to the volatiles would ever occur.

Table 17. Summary of Estimated Carcinogenic Risks for All Receptors at the Experimental Station Site

Constituent	Inhal. Risk	Non-inhal. Risk	Total Risk
INDUSTRIAL WORKERS			
Benzene	2.5×10^{-8}	—	2.5×10^{-8}
Beryllium	—	2.3×10^{-6}	2.3×10^{-6}
Methylene chloride	9.2×10^{-11}	5.9×10^{-10}	6.9×10^{-10}
PAHs	1.9×10^{-16}	5.5×10^{-5}	5.5×10^{-5}
1,1,2,2-T_4chloroethane	4.1×10^{-8}	—	4.1×10^{-8}
Tetrachloroethene	3.3×10^{-10}	5.2×10^{-8}	5.3×10^{-8}
Trichloroethene	1.8×10^{-9}	2.6×10^{-8}	2.8×10^{-8}
Vinyl chloride	3.6×10^{-7}	—	3.6×10^{-7}
	Total Carcinogenic Risk:		6×10^{-5}
RECREATIONAL USERS – Adults			
Benzene	1.9×10^{-10}	—	1.9×10^{-10}
Beryllium	—	6.2×10^{-7}	6.2×10^{-7}
Methylene chloride	7.0×10^{-13}	2.0×10^{-11}	2.0×10^{-11}
PAHs	1.4×10^{-18}	1.4×10^{-6}	1.4×10^{-6}
1,1,2,2-T_4chloroethane	3.2×10^{-10}	—	3.2×10^{-10}
Tetrachloroethene	2.5×10^{-12}	1.7×10^{-9}	1.7×10^{-9}
Trichloroethene	1.3×10^{-11}	8.6×10^{-10}	8.7×10^{-10}
Vinyl chloride	2.8×10^{-9}	—	2.8×10^{-9}
	Total Carcinogenic Risk:		2×10^{-6}
RECREATIONAL USERS – Children			
Benzene	1.3×10^{-10}	—	1.3×10^{-10}
Beryllium	—	2.4×10^{-7}	2.4×10^{-7}
Methylene chloride	4.8×10^{-13}	1.4×10^{-11}	1.4×10^{-11}
PAHs	9.7×10^{-19}	1.1×10^{-6}	1.1×10^{-6}
1,1,2,2-T_4chloroethane	2.1×10^{-10}	—	2.1×10^{-10}
Tetrachloroethene	1.7×10^{-12}	1.2×10^{-9}	1.2×10^{-9}
Trichloroethene	9.1×10^{-12}	6.0×10^{-10}	6.1×10^{-10}
Vinyl chloride	1.9×10^{-9}	—	1.9×10^{-9}
	Total Carcinogenic Risk:		1×10^{-6}

Risks to potential recreational users are very low and are therefore of no consequence at this site because the future use of the site does not include recreational activities. Remediation of the sediments is not needed as long as the site remains in industrial use because the sediments are not a source of potential exposure for industrial workers and because the risk assessment indicates very small risks to recreational users due to contact with sediments.

IV. CALCULATION OF REMEDIATION GOALS FOR CONSTITUENTS OF CONCERN

Remediation goals are calculated to represent residual constituent concentrations that will not result in excess risk or hazard to receptors at a site. The risk assessment for the Experimental Station demonstrated that the site does not present unacceptable non-carcinogenic health hazards. Therefore, there is no need to estimate remediation goals on the basis of non-carcinogenic health hazards.

However, the risk assessment indicated carcinogenic risks to industrial workers that are near the high end of the range considered acceptable by EPA (i.e., 10^{-6} to 10^{-4}). The results of the risk assessment indicate that beryllium and PAHs present more than 99 percent of the total risk at the site and are therefore the only compounds for which estimating remedial goals in soils is appropriate. Remediation goals for constituents in ground water have also been estimated or identified.

The steps in calculating remediation goals based on potential carcinogenic health effects are:

- identification of standards or requirements for constituents of concern,
- selection of the target carcinogenic risk, and
- estimation of remediation goals for constituents without standards or other requirements based on the selected target carcinogenic risk.

A. Identification of Standards for Constituents of Concern

Maximum contaminant levels (MCLs) have been established by EPA to monitor the level of various constituents in drinking water supplies. MCLS are designed to prevent potential adverse human health effects due to exposure to constituents in ground water. EPA derives MCLs based not only on health considerations, but also on (1) technical feasibility and (2) the costs associated with applying the chosen technology (EPA 1990b). The ability of the analytical technology to detect the constituent of concern is also weighed when establishing an MCL. Constituents that the EPA deems to be potential carcinogens are regulated using MCLs such that the excess risk of cancer does not exceed 10^{-4}, the upper bound of the risk range considered acceptable by EPA (1990b).

MCLs have been either promulgated or proposed for eight of the ten constituents of concern in ground water. Final MCLs exist for vinyl chloride, carbon tetrachloride, trichloroethene, and benzene (EPA 1989g). In addition, MCLs for methylene chloride, t-1,2-dichloroethene, 1,1,2-trichloroethane, and tetrachloroethene have been proposed (EPA 1989d; EPA 1990b). Although the proposed MCLs are not final rules, and do not represent promulgated regulatory standards, it is anticipated that future decisions will not deviate substantially from these proposed MCLs. Therefore, in this analysis, the proposed MCLS have been utilized as if they are final. Proposed and final MCLs for the constituents of concern are listed in Table 18.

Ground water below the site is not currently used as a source of drinking water or for any other purpose. Furthermore, due to the small saturated thickness and low productivity of the water-bearing zones, it is extremely unlikely that the ground water below the site would be used for drinking water in the future (GeoTrans 1990). However, the MCLs are included here as appropriate goals requiring further analysis.

Table 18. Maximum Contaminant Levels for Constituents of Concern

Constituent	MCL (µg/L)
Benzene	5[1]
α-BHC	—
Carbon tetrachloride	5[1]
t-1,2-Dichloroethene	100[2]
Methylene chloride	5[3]
1,1,2,2-Tetrachloroethane	—
Tetrachloroethene	5[2]
1,1,2-Trichloroethane	5[3]
Trichloroethene	5[1]
Vinyl chloride	2[1]

[1]EPA (1989g).
[2]EPA (1989d).
[3]EPA (1990b).

B. Selection of the Target Carcinogenic Risk

Carcinogenic potency factors (CPFs) are used to calculate the carcinogenic risk as shown in the following equation (EPA 1989a):

$$Risk = (CPF)(LADD)$$

where:

Risk	Unitless excess lifetime risk of cancer due to exposure,
CPF	Carcinogenic Potency Factor $(mg/kg/day)^{-1}$, and
LADD	Lifetime average daily dose (mg/kg/day).

For Superfund sites, EPA considers total excess lifetime carcinogenic risks in the range of 10^{-6} to 10^{-4} to be acceptable (EPA 1990c). Therefore, depending on the selected Target Risk Level, remediation goals for carcinogens can be estimated for any point in this range. The target carcinogenic risk level for the Experimental Station site was set at 1×10^{-5}. This level is within the range considered acceptable by EPA. The small potential receptor populations, the remoteness of the site, and the absence of impacts of the contamination at the site on Brandywine Creek demonstrated by GeoTrans, Inc. (1990) all support a target risk level of 10^{-5}.

The results of the risk assessment presented in the previous section indicate that only the industrial worker scenario is estimated to present potential carcinogenic risks above 1×10^{-5}. Thus, health-based remediation goals were derived only for the constituents and media identified in the industrial exposure scenario. The total target carcinogenic risk level (1×10^{-5}) was apportioned among the ten constituents of concern in ground water (i.e., 1×10^{-6} risk per constituent) and among the two constituents of concern in soils (i.e., 5×10^{-6} risk per constituent). We used these target risk levels to estimate health-based target concentrations for constituents in ground water and soils.

C. Calculation of Health-Based Remediation Goals

Estimated lifetime average daily doses (LADDs) of constituents can be expressed as a function of the concentration of the constituent and an exposure factor that consists of all other exposure variables. For example:

$$\text{Dermal LADD (mg/kg/day)} = (CS)(F_{derm})$$

where:

CS Constituent concentration in soil (mg/kg), and
F_{derm} Exposure factor for dermal contact with soil (d^{-1}).

Appendix 3 details the derivation of exposure factors for all exposure pathways. Since carcinogenic risk is estimated by multiplying the LADD by the appropriate CPF, carcinogenic risk can be expressed as:

$$\text{Risk} = (CS)(F_{derm})(CPF)$$

where:

CPF Carcinogenic potency factor $(mg/kg/d)^{-1}$.

This equation can be rearranged to solve for the concentration in soil that corresponds to a given target risk level in order to estimate a remediation goal:

$$\text{Remediation goal} = \frac{\text{Risk}}{(F_{derm})(CPF)}$$

Remediation goals can also be estimated for multiple exposure pathways, as in the case of dermal contact with and ingestion of soils:

$$\text{Remediation goal} = \frac{\text{Risk}}{(F_{derm} + F_{ing})(CPF)}$$

where:

F_{ing} Exposure factor for ingestion of soils (day^{-1}).

1. Health-Based Remediation Goals for Ground Water

The total target carcinogenic risk level of 1×10^{-5} was apportioned among the ten constituents of concern in ground water, resulting in a target risk of 1×10^{-6} per constituent. Health-based remediation goals for the two constituents in ground water for which no proposed or final MCLs exist (i.e., 1,1,2,2-tetrachloroethane and α-BHC) were estimated using exposure assumptions for typical residential exposure. Even though the ground water on the site is not currently used as drinking water by employees, a residential exposure scenario for ground water was developed because doing so makes the health-based remediation goals comparable to the MCLs. The formula for the exposure factor for drinking water and the values of the exposure variables used to evaluate the exposure factor are listed in Appendix 3. Table 19 lists the remediation goals for constituents in ground water estimated at a risk of 1×10^{-6} per constituent. As noted in Section IV(A), ground water is unlikely to be used as drinking water at this site. The remediation goals listed in Table 19 are retained for further consideration acknowledging this limitation.

2. Health-Based Remediation Goals for Soil

Remediation goals for two of the constituents of concern in soil (beryllium and PAHs) were estimated for a total target risk of 1×10^{-5}, corresponding to a risk of 5×10^{-6} per constituent. Remediation goals were estimated using the industrial worker exposure scenario. Development of the exposure factors used to estimate these remediation goals is discussed in Appendix 3. The estimated remediation goals are summarized in Table 20.

Because the industrial scenario did not include potential exposures to sediments, and the risk assessment demonstrated that exposure to beryllium in sediments did not lead to unacceptable risks for recreational users, no remediation goal for beryllium in sediments was estimated. Remediation goals for methylene

Table 19. Health-Based Remediation Goals for Constituents in Ground Water

Constituent	Remediation Goal (µg/L)
α-BHC	0.013
1,1,2,2-Tetrachloroethane	0.4

Table 20. Health-Based Remediation Goals for Constituents in Soil

Constituent	Remediation Goal (mg/kg)
Beryllium	0.86
PAHs (Benzo[a]pyrene)	0.79

chloride, tetrachloroethene, and trichloroethene were not estimated because the risk assessment indicated that the presence of these compounds does not contribute to the risks presented by the site.

D. Groundwater Remediation Goals Based on Discharge to Brandywine Creek

Since the ground water at this site is not used as a source of drinking water, it might be argued that the MCLs and health-based remediation goals should not be applied to constituents in the ground water. However, the ground water under the experimental station flows toward and discharges into the Brandywine Creek. Therefore, it is appropriate to consider the impact of the groundwater discharge to Brandywine Creek. For constituents of concern in Brandywine Creek, two sets of standards apply: (1) Ambient Water Quality Criteria established to protect aquatic life, and (2) MCLs.

Ambient Water Quality Criteria (AWQC) are established by EPA under provisions of the Clean Water Act. AWQC are set so as to protect aquatic life and, as such, represent contaminant concentrations that will not be harmful to the environment. When insufficient data exist to estimate an AWQC, the lowest effect level or concentration taken from the literature, termed an LEC, is used. LECs for eight of the ten constituents of concern in fresh water are listed in Table 21. Most of these LECs are for acute exposures. Few long-term, or chronic, LECs have been set because data are not available. The AWQCs are greater than the MCLs (see Table 18) for all constituents of concern. Therefore, applying the MCLs and human health-based remediation goals to the creek water will be more conservative and protective of human health and the environment.

Brandywine Creek is used as a source of drinking water. Therefore, we can calculate constituent concentrations in the ground water discharging to the creek that would not result in

Table 21. Ambient Water Quality Criteria for Constituents of Concern[1]

Constituent	AWQC (µg/L)
Benzene	5,300[2]
α-BHC	100[2]
Carbon tetrachloride	35,200[2]
t-1,2-Dichloroethene	—
Methylene chloride	11,000[2]
1,1,2,2-Tetrachloroethane	2,400[2]
Tetrachloroethene	840[3]
1,1,2-Trichloroethane	9,400[2]
Trichloroethene	45,000[2]
Vinyl chloride	—

[1]EPA (1991).
[2]Acute LEC.
[3]Chronic LEC.

concentrations in the creek in excess of the MCLs and health-based remediation goals. The groundwater discharge to the Brandywine Creek has been estimated to range from 2022 ft^3/d (0.0234 ft^3/s) to 4345 ft^3/d (0.05 ft^3/s) (GeoTrans 1990). The minimum daily flow in Brandywine Creek during the past 42 years was 50 ft^3/s and the average flow was 477 ft^3/s (GeoTrans 1990). As a conservative estimate of the dilution of ground water discharging into the creek, the ratio of the minimum creek flowrate to the maximum ground water discharge rate was calculated:

Dilution factor = (50 ft^3/s) / (0.05 ft^3/s)

Dilution factor = 1000

Thus, groundwater concentrations of constituents can be one thousand times greater than the MCLs and health-based remediation goals applied to Brandywine Creek. Table 22 lists the resulting estimates of remediation goals for constituents in ground water based on impacts to Brandywine Creek.

E. Remediation Goals for Constituents of Concern at the Experimental Station Site

Remediation goals for all constituents of concern in all environmental media are summarized and compared to detected concentrations in Table 23.

For ground water used as drinking water, the remediation goals for constituents of concern are final or proposed MCLs, where they exist. For the remaining constituents of concern in ground water, the health-based remediation goals listed in Table 19 are recommended for the Experimental Station site. Detected concentrations of all constituents of concern exceed these remediation goals, indicating that remediation of ground water may be necessary if it is to be used as a drinking water source. Remediation goals for ground water based on discharge to

Table 22. Groundwater Remediation Goals Based on Discharge to Brandywine Creek

Constituent	Remediation Goal (µg/L)
Benzene	5,000
α-Benzene hexachloride	13
Carbon tetrachloride	5,000
t-1,2-Dichloroethene	100,000
Methylene chloride	5,000
1,1,2,2-Tetrachloroethane	400
Tetrachloroethene	5,000
1,1,2-Trichloroethane	5,000
Trichloroethene	5,000
Vinyl chloride	2,000

Table 23. Remediation Goals and Detected Concentrations of Constituents of Concern at the Experimental Station Site

Constituent	Units	Remediation Goal	Detected Concentrations
GROUND WATER[1]			
Benzene	µg/L	5; 5,000	1J – 300
α-BHC	µg/L	0.013; 13	0.05J – 0.06
Carbon tetrachloride	µg/L	5; 5,000	<5 – 680
t-1,2-Dichloroethene	µg/L	100; 100,000	4J – 840
Methylene chloride	µg/L	5; 5,000	2J – 130
1,1,2,2-Tetrachloroethane	µg/L	0.4; 400	4J – 5100
Tetrachloroethene	µg/L	5; 5,000	4J – 530
1,1,2-Trichloroethane	µg/L	5; 5,000	<5 – 130
Trichloroethene	µg/L	5; 5,000	3J – 7700
Vinyl chloride	µg/L	2; 2,000	3J – 610
SOIL			
Beryllium	mg/kg	0.86	0.15J – 0.41
PAHs (Benzo[a]pyrene)	µg/kg	790	99 – 46960

[1]For constituents in ground water, the first goal was set assuming that the ground water is used as drinking water, and the second is based on discharges to Brandywine Creek. Refer to text.

"J" indicates an estimated concentration that is below the limit of detection for that chemical.
"<" indicates a non-detect at the given limit of detection.

Brandywine Creek are greater than observed concentrations for all constituents except 1,1,2,2-tetrachloroethane, indicating that remedial measures are not required to protect the surface water.

The remediation goals for constituents in soil are those estimated under the industrial worker exposure scenario, which will provide adequate protection against adverse health effects for industrial workers. The maximum detected concentration of beryllium in soil (0.41 mg/kg) is below the estimated remediation goal (0.86 mg/kg), indicating that any remediation effort considered at the Experimental Station site need only consider PAHs in soils.

As stated above, no remediation goal for sediments has been estimated because no exposure to sediments is anticipated for industrial workers. Remediation of sediments is not necessary if the Experimental Station site remains in its current use.

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APPENDICES

Appendix 1
CALCULATION OF EQUIVALENT CONCENTRATIONS OF BENZO[a]PYRENE FOR MIXTURES OF PAHs.
\LOTUS\DUPPAH.WK1
5/29/91

PAH	Relative Potency Factor	M-COMP	K-2	1A	1AD	1B	2A	2A RE
Anthracene	E	20	780	231.5 N	234.5 N	216.5 N	800	1100
Benzo[a]anthracene	0.145	180 N	1600	231.5 N	234.5 N	216.5 N	4000	4900
Benzo[a]pyrene	1.0	180 N	1500	231.5 N	234.5 N	216.5 N	4700	5100
Benzo[b]fluoranthene	0.14	180 N	1200	231.5 N	234.5 N	216.5 N	7000	8200
Benzo[k]fluoranthene	0.066	180 N	1300	231.5 N	234.5 N	216.5 N	7000	5700
Benzo[g,h,i]perylene	0.022	180 N	400	231.5 N	234.5 N	216.5 N	196.35 N	392.7 N
Chrysene	0.0044	100	1900	231.5 N	234.5 N	216.5 N	4200	5400
Fluoranthene	D	54	2400	231.5 N	234.5 N	216.5 N	4500	6500
Fluorene	D	22	260	231.5 N	234.5 N	216.5 N	280	320
Indeno[1,2,3-cd]pyrene	0.232	180 N	430	231.5 N	234.5 N	216.5 N	196.35 N	770
Phenanthrene	D	110	2200	231.5 N	234.5 N	216.5 N	3000	3900
Pyrene	0.081	120	3700	231.5 N	234.5 N	216.5 N	5400	6500
BaP equivalents (ug/kg)		299.06	2402.42	391.33	396.40	365.97	7227.75	8072.24
				Average:	393.86		Average:	7650.00

NOTES: Concentrations carrying the "N" designation represent non-detects.
The value indicated is equal to one-half the detection limit for that sample.

For PAHs with no indicated relative potency factor, the letter refers to the carcinogen classification listed in EPA (1985): "D" – Not classified, "E" – No evidence of human carcinogenicity.

Appendix 1 (cont'd)
CALCULATION OF EQUIVALENT CONCENTRATIONS OF BENZO[a]PYRENE FOR MIXTURES OF PAHs.

PAH	Relative Potency Factor	2B	3A	3AD	3B	3BD	4A	4B
Anthracene	E	206 N	198.5 N	198.5 N	198.5 N	231.5 N	211 N	20000
Benzo[a]anthracene	0.145	24	198.5 N	198.5 N	198.5 N	231.5 N	33	42000
Benzo[a]pyrene	1.0	23	198.5 N	198.5 N	198.5 N	231.5 N	32	27000
Benzo[b]fluoranthene	0.14	40	198.5 N	198.5 N	198.5 N	231.5 N	53	27000
Benzo[k]fluoranthene	0.066	206 N	198.5 N	198.5 N	198.5 N	231.5 N	211 N	31000
Benzo[g,h,i]perylene	0.022	206 N	198.5 N	198.5 N	198.5 N	231.5 N	211 N	5200
Chrysene	0.0044	57	198.5 N	198.5 N	198.5 N	231.5 N	92	42000
Fluoranthene	D	30	198.5 N	198.5 N	198.5 N	231.5 N	25	78000
Fluorene	D	206 N	198.5 N	198.5 N	198.5 N	231.5 N	211 N	10000
Indeno[1,2,3-cd]pyrene	0.232	206 N	198.5 N	198.5 N	198.5 N	231.5 N	211 N	5800
Phenanthrene	D	52	198.5 N	198.5 N	198.5 N	231.5 N	65	75000
Pyrene	0.081	31	198.5 N	198.5 N	198.5 N	231.5 N	29	79000
BaP equivalents (ug/kg)		100.76	335.54	335.54	335.54	391.33	114.48	46959.80
			Average:	335.54	Average:	363.44		

Appendix 1 (cont'd)
CALCULATION OF EQUIVALENT CONCENTRATIONS OF BENZO[a]PYRENE FOR MIXTURES OF PAHs.

PAH	Relative Potency Factor	5A	5B	6A	6AD	6B	6BD
Anthracene	E	48	213.5 N	219.5 N	234.5 N	2600	600
Benzo[a]anthracene	0.145	190	28	20	47	6600	2600
Benzo[a]pyrene	1.0	180	23	18	19	5100	2200
Benzo[b]fluoranthene	0.14	180	213.5 N	38	28	7800	3900
Benzo[k]fluoranthene	0.066	190	213.5 N	219.5 N	234.5 N	241.5 N	219.5 N
Benzo[g,h,i]perylene	0.022	71	213.5 N	219.5 N	234.5 N	960	460
Chrysene	0.0044	220	26	38	234.5 N	6200	2700
Fluoranthene	D	340	41	26	17	13000	3700
Fluorene	D	198.5 N	213.5 N	219.5 N	234.5 N	1200	2200
Indeno[1,2,3-cd]pyrene	0.232	61	213.5 N	219.5 N	234.5 N	1200	540
Phenanthrene	D	170	213.5 N	27	234.5 N	11000	2400
Pyrene	0.081	390	43	29	28	12000	4300
BaP equivalents (ug/kg)		293.56	128.87	98.98	108.07	8463.74	3633.07
				Average:	103.53	Average:	6048.40

Appendix 1 (cont'd)
CALCULATION OF EQUIVALENT CONCENTRATIONS OF BENZO[a]PYRENE FOR MIXTURES OF PAHs.

PAH	Relative Potency Factor	7A (App IX)	7A	7AD	8A	8B
Anthracene	E	62	91	180	170	292.5 N
Benzo[a]anthracene	0.145	240	380	540	350	57
Benzo[a]pyrene	1.0	190	300	390	280	52
Benzo[b]fluoranthene	0.14	150	250	380	230	45
Benzo[k]fluoranthene	0.066	230	201 N	196 N	210	292.5 N
Benzo[g,h,i]perylene	0.022	400	110	140	120	292.5 N
Chrysene	0.0044	240	400	540	370	64
Fluoranthene	D	450	630	630	710	110
Fluorene	D	20	201 N	196 N	86	292.5 N
Indeno[1,2,3-cd]pyrene	0.232	52	100	130	130	292.5 N
Phenanthrene	D	200	360	640	720	292.5 N
Pyrene	0.081	400	690	930	660	100
BaP equivalents (ug/kg)		315.30	486.64	645.38	464.70	168.55
			Average:	482.44		

APPENDIX 2. Estimation of Concentrations of Volatilized Constituents at the Experimental Station Site

A. Model to Estimate Emissions of Constituents Volatilizing from the Groundwater Seep

Emissions of volatile constituents from the groundwater were estimated using the method described below, which was taken from Thomas (1982). The resulting estimated emission rates very likely overstate actual emission rates because it was assumed that volatilization occurs all year long at a temperature of 25°C (77°F). Figure 2-1 summarizes the relevant physical-chemical data for all of the constituents of concern in the groundwater seep and illustrates the method of calculation. Physical-chemical data were obtained primarily from EPA (1986).

The estimated emission rate of a volatile constituent from a dilute solution is expressed as:

$$E\ (g/s) = (K_L)(C_L)(A)(CF1)(CF2)$$

where:

- E Emission rate (g/s),
- K_L Overall liquid phase mass transfer coefficient (cm/s),
- C_L Concentration in liquid phase ($\mu g/L$),
- A Surface area (cm^2),
- CF1 Conversion factor (1 L/1000 cm^3), and
- CF2 Conversion factor (1 g/10^6 μg).

The overall liquid phase mass transfer coefficient, K_L, is calculated as follows:

$$1/K_L = (1/k_l + 1/H'k_g)/CF3$$

where:

- K_L Overall liquid-phase mass transfer coefficient (cm/s),
- k_l Liquid-phase exchange coefficient (cm/hr),
- H' Dimensionless Henry's constant,
- k_g Gas-phase transfer coefficient (cm/hr), and
- CF3 Conversion factor (1 hr/3600 s).

The dimensionless Henry's constant is calculated from:

$$H' = H/RT$$

where:

H'	Dimensionless Henry's constant,
H	Henry's constant ($atm \cdot m^3/mol$),
R	Universal gas constant ($atm \cdot m^3/mol \cdot K$), and
T	Temperature (°K).

The liquid-phase exchange coefficient, k_l, for volatile constituents with molecular weights above 65 g/mol is calculated as follows when the wind velocity is greater than 1.9 m/s:

$$k_l = 23.51 \frac{Vc^{0.969}}{Z^{0.673}} (32/MW)^{0.5} e^{0.526(Vw - 1.9)}$$

where:

k_l	Liquid-phase exchange coefficient (cm/hr),
Vc	Velocity of the current (m/s),
Z	Depth of the flowing water (m),
MW	Molecular weight (g/mol), and
Vw	Wind velocity (m/s).

Finally, the gas-phase exchange coefficient, k_g, is calculated from Southworth's equation:

$$k_g = 1137.5 \ (Vw + Vc) \ (18/MW)^{0.5}$$

where:

k_g	Gas-phase exchange coefficient (cm/hr), and

the other variables are as defined above.

To perform the appropriate calculations, the following assumptions were made:

- The average wind velocity was assumed to be 2.2 m/s, or approximately 10 mph.
- Based on information obtained from GeoTrans personnel, the "stream" resulting from the seep was assumed to be

6 inches wide and 100 feet long, flowing at a rate of 1 cm/s and having a depth of 1 cm.

- The average temperature was assumed to be 25°C.

B. Model to Estimate Emissions of Constituents Volatilizing from the Soil

Emissions of constituents volatilizing from soil were modeled as a function of surface soil concentration using the method presented in this section. Resulting emission rates are very likely to overstate actual emission rates because an average temperature of 25°C was assumed. Figure 2-2 summarizes the physical-chemical information needed to perform these calculations and illustrates the method of calculation. Physical-chemical data were obtained from EPA (1986).

The emission rate of volatilized constituents can be estimated using the following equation derived from principles in Bird et al. (1960):

$$E\ (g/s) = (D)\ \frac{DEL}{K}\ \frac{P}{RTL}\ \ln\ \frac{(1 - AA \cdot Yi)}{(1 - AA \cdot Yo)}\ (MW)(A)$$

where:

E	Emission rate of volatilized constituent (g/s),
D	Diffusion coefficient (cm^2/sec),
DEL	Fraction of macropores in soil (assumed 0.001 due to pavement cover),
K	Tortuosity factor for a porous medium (average value of 3 assumed),
P	Total pressure (760 mmHg),
R	Gas constant (62,631 mmHg·cm^3/mol·°K),
T	Absolute temperature (298 °K),
L	Depth of cover (15 cm, average thickness of pavement),
AA	Chemical dependent model parameter,
Yi	Mole fraction of chemical in soil pores,
Yo	Mole fraction of chemical at soil-air interface,
MW	Molecular weight of chemical (g/mol), and
A	Surface area (cm^2).

The parameter AA is calculated as follows for each constituent of concern:

$$AA = 1 - (MW/MW_{air})^{0.5}$$

where:

MW_{air} Molecular weight of air: 28.8 g/mole.

Yi is estimated for each constituent using the following formula:

$$Yi = (CS)(CF4)\frac{p^*}{P}$$

where:

CS Constituent concentration in soil (mg/kg),
CF4 Conversion factor: 10^{-6} kg/mg,
p^* Vapor pressure (mmHg), and
P Total pressure (mmHg).

The formula to estimate emission rates can be simplified with two assumptions. First, existing concentrations of volatiles in air at the soil/air interface are assumed to be zero in order to maximize estimates of emission rates. Second, because Yi is a small number (compared to 1.0), the following simplification can be used:

$$\ln (1 + x) \approx x$$

for small x. Therefore,

$$\ln (1 - AA \cdot Yi) = \ln [1 + (-AA) \cdot Yi] \approx (-AA) \cdot Yi.$$

Thus, the simplified form of the formula to estimate emission rates of constituents volatilizing from soil is:

$$E\ (g/s) = (D)\frac{DEL}{K}\frac{P}{RTL}(-AA)(Yi)(MW)(A)$$

Because most of the site is covered with soil, the fraction of macropores was assumed to be 0.001 (or 0.1 percent) and the thickness of the pavement was assumed to be 15 cm (6 inches). For simplicity, the contaminated area of the site was assumed to be a square 100 meters on a side.

C. Estimation of Average Concentrations of Volatilized Constituents from Emission Rates

Estimated emission rates can be converted to average ambient air concentrations using a Gaussian dispersion model (EPA 1988):

$$C_v = \frac{(E)(CF5)}{\pi\ \sigma_z\ \sigma_y\ Vw}$$

where:

Cv	Concentration of volatilized constituent at a given distance from the emission ($\mu g/m^3$),
E	Volatilization emission rate (g/s),
CF5	Conversion factor (10^6 $\mu g/g$),
σ_z	Dispersion coefficient in the crosswind direction (m),
σ_y	Dispersion coefficient in vertical direction (m), and
Vw	Wind velocity (m/s).

Dispersion coefficients are evaluated as a function of distance. It was assumed that the conditions at the Experimental Station placed the site in stability category "C." At a distance of 100 meters (the minimum distance for which dispersion coefficients are available) from the emission the corresponding dispersion coefficients are: σ_z = 7.5 m and σ_y = 12 m (EPA 1988). The average wind speed was assumed to be 2.2 m/s. Estimated concentrations of all volatilized constituents are listed in Figures 2-1 and 2-2. Exposures and risks associated with inhalation of benzo[a]pyrene were not evaluated because the estimated vapor concentration of benzo[a]pyrene was so low.

VOLATILIZATION FROM SEEP -- Est. vapor concs. using MAX in 2A

\LOTUS\DUPSEEP.WK1
4/22/91

Gas constant:	8.2E-05	(atm-m3/mol-K)
Temperature:	298	K
Wind velocity:	2.2	m/s
Current velocity:	0.001	m/s
Depth of seep:	0.001	m
Seepage area:	46500	cm2 -- assuming 100 ft x 0.5 ft
Crosswind dispersion coeff. (at 100 m):	12	m -- assuming Class C stability
Vertical dispersion coeff. (at 100 m):	7.5	m -- assuming Class C stability

	MW (g/mol)	Henry's Constant (atm-m3/mol)	Dim'less Henry's	kL (cm/hr)	kg (cm/hr)	KL (cm/s)	Conc. in GW.* (ug/L)	Emission rate (g/s)	Vapor Conc. (ug/m3)
Benzene	78	5.59E-03	2.3E-01	2.28	1203	6.3E-04	270	7.9E-06	1.3E-02
t-1,2-Dichloroethene	97	6.56E-03	2.7E-01	2.05	1079	5.6E-04	840	2.2E-05	3.5E-02
Methylene chloride	85	2.03E-03	8.3E-02	2.19	1152	5.9E-04	21	5.8E-07	9.3E-04
1,1,2,2-T4Cethane	168	3.81E-04	1.6E-02	1.55	820	3.9E-04	130	2.3E-06	3.7E-03
PCE	168	2.59E-02	1.1E+00	1.55	820	4.3E-04	52	1.0E-06	1.7E-03
TCE	131	9.10E-03	3.7E-01	1.76	928	4.9E-04	70	1.6E-06	2.5E-03
Vinyl chloride	63	8.19E-02	3.4E+00	2.54	1338	7.0E-04	410	1.3E-05	2.2E-02

*Max in MW-2A.

Figure 2-1. Estimation of Average Concentrations of Constituents Volatilizing from the Groundwater Seep

Figure 2-2. Estimation of Average Concentrations of Constituents Volatilizing from the Soil

VOLATILIZATION FROM SOIL -- Est. vapor concs.

LOTUS\DUPSOIL.WK1
5/24/91

Fraction of macropores, DEL:	0.001
Tortuosity factor, K:	3
Pressure, P (mmHg):	760
Gas constant, R (mmHg-cm3/mol-K):	62631
Temperature, T (K):	298
Depth of cover, L (cm):	15
Area, A (cm2):	1E+08

	PCE	B[a]P	Methyl. chloride	TCE
Molecular weight, MW (g/mol):	166	252	85	131
Diffusivity, D (cm2/s):	0.07852	0.06373	0.1083	0.08606
Alpha, AA:	-1.40	-1.96	-0.72	-1.13
Vapor pressure, p* (mmHg):	19	5.6E-09	362	57.9
Rep. soil conc, CS (ug/kg):	1109	8710	85.6	2557
Mole fraction in pores, Yi:	2.8E-08	6.4E-17	4.1E-08	1.9E-07
Emission rate, E (g/s):	4.6E-08	1.8E-16	2.4E-08	2.3E-07

Wind velocity (m/s):	2.2	
Crosswind disp. coeff. (@100 m) (m):	12	Class C
Vertical disp. coeff. (@100 m) (m):	7.5	Class C

Air concentration (ug/m3):	7.4E-05	2.9E-13	3.9E-05	3.6E-04

conservative and it ensures that the health-based remediation goals for ground water will be comparably protective to the MCLs.

B. **Dermal Contact Exposure Factor**

For dermal contact with soils, estimated intakes were calculated using the following formula derived from EPA (1989a):

$$\text{Dermal LADD (mg/kg/day)} = (CS)(F_{derm})$$

F_{derm} is defined as follows:

$$F_{derm} = \frac{(CF)(SA)(AF)(ABS)(EF)(ED)}{(BW)(AT)}$$

where:

CF Conversion factor (10^{-6} kg/mg),
SA Skin surface area available for contact (cm^2/day),
AF Soil to skin adherence factor (mg/cm^2),
ABS Relative dermal absorption fraction,
EF Exposure frequency (d/yr),
ED Exposure duration (yr),
BW Body weight (kg), and
AT Period over which exposure is averaged (days).

C. **Soil Ingestion Exposure Factor**

For ingestion of soils, estimated intakes were calculated using the following formula derived from EPA (1989a):

$$\text{Soil Ingestion LADD (mg/kg/day)} = (CS)(F_{ing})$$

F_{ing} is defined as follows:

$$F_{ing} = \frac{(IR)(CF)(FI)(EF)(ED)}{(BW)(AT)}$$

where:

IR Soil ingestion rate (mg/d),
CF Conversion factor (10^{-6} kg/mg),
FI Fraction ingested from contaminated source,
EF Exposure frequency (d/yr),

ED Exposure duration (yr),
BW Body weight (kg), and
AT Period over which exposure is averaged (days).